PhD Thesis

A Multimethod analysis of the Phenomenon of Peak-Oil

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Supervisors:

Dr. Emilio Padilla Rosa

Dr. Klaus Hubacek

September 2012

Institut de Ciència i Tecnologia Ambientals (ICTA)

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Abstract

Peak-Oil is a complex, often misunderstood phenomenon. After clarifying that Peak-Oil is both a stock as well as a flow problem, the concepts of resource quality and quantity are offered for getting a grasp of the many below and above ground issues that influence its timing and possible impacts. A review of the latest evidence suggests that there is a significant risk of Peak-Oil occurring before 2020, giving us little time for adaptation. Systems theory and thermodynamics illustrate that this is a serious problem, as we may not solely rely on other energy sources for substitution or efficiency improvements. The resilience literature therefor recommends adaptive resource management processes in cases of dependencies on risky resources, as in our case of oil for the world economy. The lack of appropriate institutional response and development of adaptive policies or contingency plans is therefore rather surprising. A first attempt of an institutional analysis, speculates that this may be due to the dominant paradigm in neoclassical economic theory of relative resource scarcity, governance of non-renewable resources via markets and technological optimism. For this reason, a detour into philosophy and the analysis of surveys is taken in order to investigate the different possible attitudes towards technology, their origins and distribution among sustainability scientists. One main contribution of this text to the present Peak-Oil situation is the in-depth exploration and application of Input-Output analysis for estimating potential impacts and vulnerabilities of world economic systems to Peak-Oil. Such analysis is the first step towards adaptive resource management; it is about starting to get to know the system. The reproduced case studies show how certain clusters of industries seem to be vulnerable to Peak-Oil (e.g. transport, petrochemicals, wholesale and retail trade, etc.) and because of their importance within the structure of the economy render the entire economic system vulnerable to the phenomenon. Such information is of utter importance for designing adaptive policies. Finally the radical resource base adaptive policy option of economic degrowth towards a steady state economy (SSE) is presented and a settlement of an old dispute between Herman Daly and Nicolas Georgescu-Roegen offered. The SSE is defined as an unattainable goal, which can never actually be reached but can and should be approximated.

Keywords

Peak-Oil, Impact and Vulnerability Analysis, Input-Output-Analysis, Attitudes towards technology, De-growth, SSE, Institutional Analysis, Resilience, Systems Theory.

Resumen

Un análisis multi-metodológico del fenómeno de Peak-Oil

El concepto de *Peak-Oil* (el cénit del petróleo) es complejo y a menudo malentendido. Después de aclarar que el *Peak-Oil* es tanto un problema de estocs como de flujos, se ofrecen los conceptos de calidad y cantidad del recurso para facilitar la comprensión de la multitud de temas que influyen en el momento del cénit del petróleo y sus posibles impactos. Una revisión de la literatura y las últimas evidencias sugieren que hay un alto riesgo de que el *Peak-Oil* ocurra antes de 2020, dejando poco tiempo para la adaptación. La teoría de los sistemas y la termodinámica muestran que esto es un problema grave, dado que no podemos confiar únicamente en otros recursos energéticos como substitutos o en la mejora de la eficiencia. Es por esto que en la literatura sobre resiliencia y vulnerabilidad se recomiendan procesos de adaptación en la gestión de recursos en los casos de dependencias a recursos de riesgo (como es el caso de nuestra economía respecto al petróleo). Sorprende, por tanto, la ausencia de respuestas institucionales adecuadas y la falta de políticas de adaptación y planes de emergencia. Una primera aproximación mediante un análisis institucional de esta situación especula con que esto sea debido al paradigma dominante en la economía neoclásica, de la escasez relativa, a la gestión de los recursos no renovables mediante los mercados y al optimismo tecnológico. Por este motivo, se analiza la filosofía y se realizan encuestas para investigar las diferentes posturas posibles frente a la tecnología; sus orígenes y su importancia entre los diferentes científicos de la sostenibilidad.

Una de las contribuciones principales de este texto en relación a la situación actual ante el cénit de petróleo es que realiza una rigorosa exploración y aplicación del análisis input-output para evaluar los efectos potenciales y las vulnerabilidades del sistema económico mundial. Este tipo de análisis son un primer paso hacia una gestión adaptativa de recursos, porque ayudan a entender el sistema energético en el que vivimos. Los casos de estudio presentados demuestran que ciertos grupos de industrias parecen particularmente vulnerables ante el cénit de petróleo (p.ej. transporte, petroquímica, comercio, etc.). Industrias que, por la importancia que tienen en el sistema económico, causan que el sistema entero se vuelva vulnerable. Este tipo de información es enormemente importante para diseñar políticas adaptativas. Finalmente se presenta un modelo radical de políticas para la adaptación a la base de recursos: el decrecimiento económico hacia una economía del estado estacionario. Se aclara, además, un viejo conflicto entre Herman Daly y Nicolas Georgescu-Roegen. La economía del estado estacionario se define como una ‘meta inalcanzable’, a la que nunca se puede llegar pero a la que se puede y deberíamos aproximarnos.

Palabras clave

Peak-Oil, cenit del petróleo, análisis de impactos y vulnerabilidad, Análisis Input-Output (IO), posturas frente a la tecnología, decrecimiento, economía del estado estacionario, análisis institucional, resiliencia, teoría de los sistemas

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Declaration

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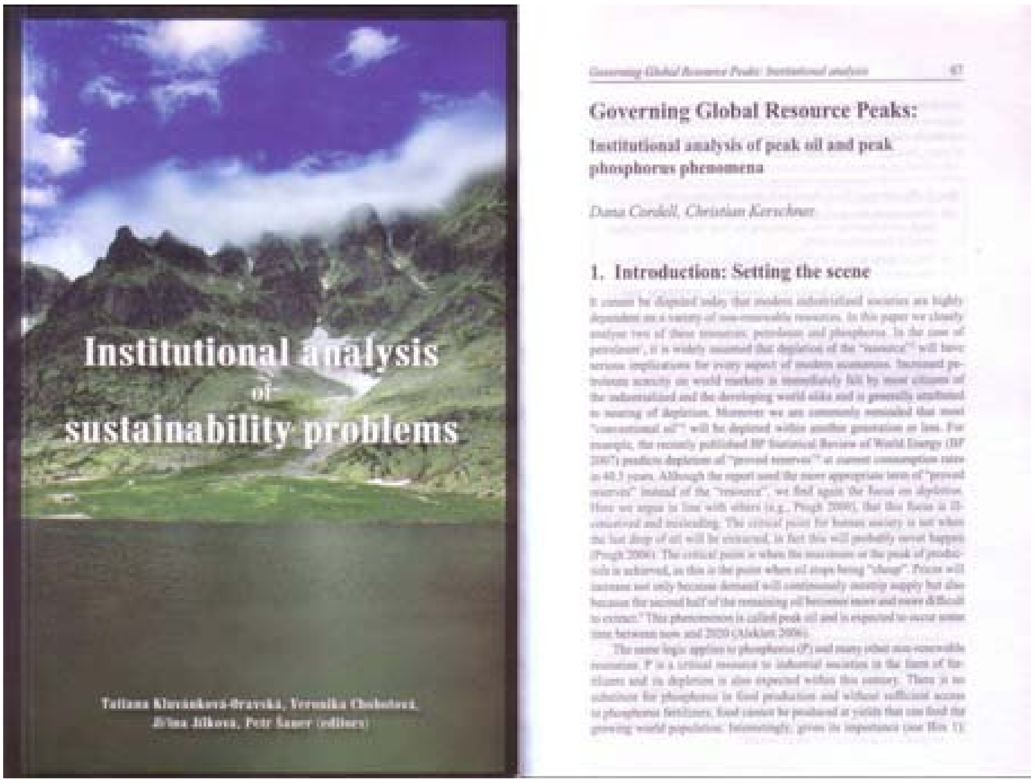

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Governing Global Resource Peaks:

Institutional analysis of peak oil and peak phosphorus phenomena

Dana Cordell, Christian Kerschner

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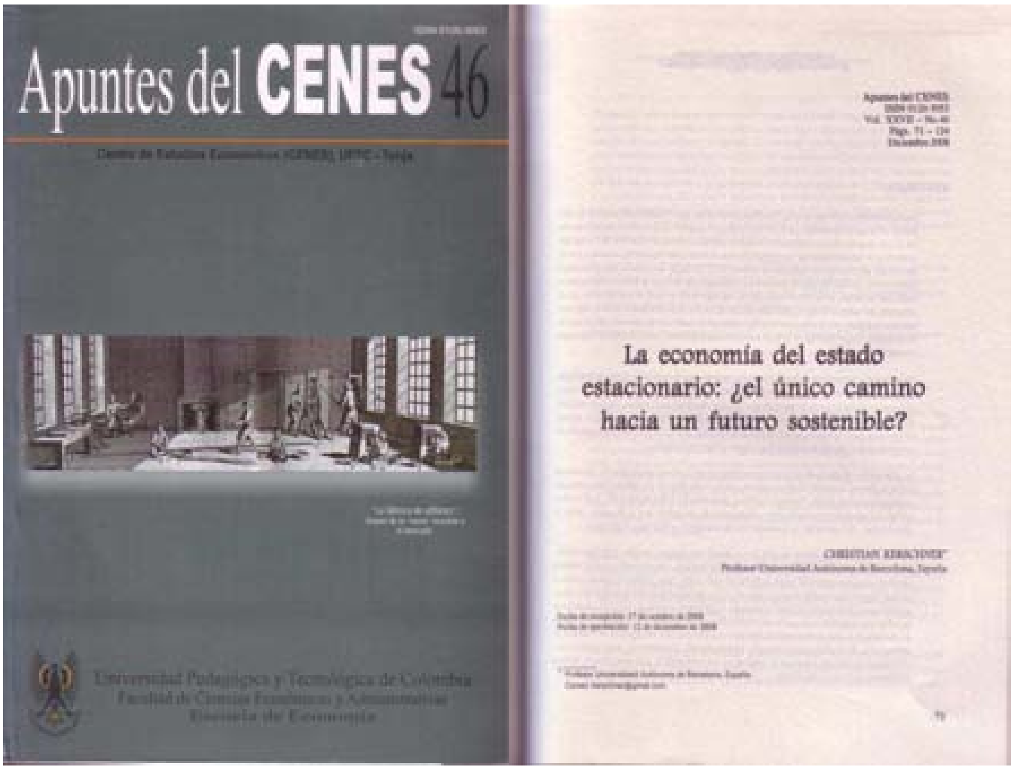

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PART 1

Background

1 Introduction – Analysing Peak Oil

1.1 Peak Oil: potential impacts, vulnerabilities, technology and policy

"*You can compare our current cheap-oil-economy to a race car, which can go 400km/h. Peak-Oil is like taking off one of its wheels. That race car then won't go at 300km/h, it simply won't go at all."* (Dennis Meadows 2012)

Given the potential scale and implication for the world economy the phenomenon of Peak-Oil[1] is still receiving relatively little attention in the media, by policy makers and by academia. Very slowly, however, this seems to be changing, even though the word "Peak-Oil" is still not used publicly by policy makers nor is it dealt with in the appropriate institutional arenas as already argued by Cordell and Kerschner (2007) (see also Chapter 2.4). However, the different debates about when this point will be reached and if that is of any importance or not are creating more mainstream scientific and public media attention than ever.

The reactions to a recent report denying any oil scarcities in the medium to long-run illustrates the fact that Peak-Oil is slowly entering mainstream public debate. Leonardo Maugeri, associate of the Harvard Kennedy School and employed by ENI, predicts in his report (Maugeri 2012) an "unprecedented upsurge of oil production", which even led former "Peak-Oilist" George Monbiot to proclaim "there is enough to fry as all" (Monbiot 2012), or a Bloomberg Journalist to announce bullishly "everything you know about peak oil is wrong" (Kenny 2012). Maugeri's report was heavily criticised by the peak oil community (Laherrere 2012; Strahan 2012), scientific analysts (Hamilton 2012; Kerr 2012; Sorrell 2012), industry insiders (al-Huseini 2012) and other journalists (Kümmel 2011; Evans-Pritchard 2012), for being biased and overly optimistic about the future importance of shale oil and gas[2].

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[1] Both the term and the concept of „peak oil" were invented by Collin Campbell and Aleklett Kjell, when they founded ASPO (the Association for the Study of Peak Oil) in 2002. The unusual word order is due to the anecdotal fact that they did not like the sound of the acronym ASOP (CBSNews 2009). Beyond the Peak-Oil community, energy analysts and informed individuals, the term is hardly known and at times very difficult to communicate. In this text I have chosen an alternative way of spelling **Peak-Oil** (capitals and with hyphen), in order to highlight the fact that it is a proper noun, which describes an often difficult to grasp concept or phenomenon. Despite the fact that its most important raison d'être is to have a concept which is distinct from that of "depletion", all too often these terms are confused with each other.

[2] Shale oil and gas are not different to conventional oil and gas, only that it sits in small unconnected pockets surrounded by sandstone. The individual pockets do not merit drilling for them, but new fracking technology allows connecting them through hydraulic fracturing and the oil or gas can then be extracted through one single

The nature of these debates and its main protagonists have hardly changed since the seminal papers by Campbell and Laherrère (1998) and Aleklett and Campbell (2003), which revived Marion King Hubert's (1956) theory of a global peak of oil production. On the one hand there are the geologists and former petroleum industry insiders, many of which are united under the banner of the Association for the Study of Peak Oil (ASPO) (Hamilton 2005; Aleklett, Höök et al. 2010; Kerr 2011; Kerr 2012; Murray and King 2012). They argue that the maximum level of global oil production has either occurred already, or is about to occur very soon (see Chapter 2.1). Their fiercest opponent to this view is CERA (Cambridge Energy Research Analysts), headed by Daniel Yergin and acquired by IHS Inc. (Information Handling Systems) in 2004. Before that, in 1996, IHS had already taken over Collin Campbell's former client Petroconsultants S.A., for whom he had produced the report (Campbell 1997) on which he and Jean Laherrère later based their 1998 article. CERA (Jackson 2006; Owen, Inderwildi et al. 2010) and Daniel Yergin (Yergin 2011; Yergin 2011; Yergin 2012) today publish the most optimistic outlooks for future oil supplies. For Collin Campbell's personal account of this change of heart at the IHS-Petroconsultants-CERA conglomerate see Vivoda (2009).

The Peak-Oil phenomenon can be divided in *'below'* and '*above ground'* issues. The before mentioned groups around ASPO and CERA, could be regarded as the "geologists" in this debate, covering mostly "below ground" topics. The main topics of dispute here are predictions about the remaining oil (reliability of available statistical data), about yet to be found oil and about the potentials of improved exploration and extraction technologies. Even though the authors of this group also highlight the importance of Peak-Oil for our economic system, *above ground* authors are mostly (1) natural scientists (chemists, physicists, ecologists, systems theorists, energy analysts, etc.) (2) Political scientists and (3) economists (mainstream, ecological and biophysical). In all three of these camps there are *optimists* and *pessimists* regarding the (energy) future of our economic system. In group one (natural scientists) we have those who predict (possible) imminent collapse and disaster for our economic system (Odum and Odum 2001; Heinberg 2004; Newman, Beatley et al. 2009; Hall and Klitgaard 2011; Healy 2012; Sorman and Giampietro in press), being rather pessimistic about the potential of alternatives to fossil fuels (renewables and nuclear) and efficiency improvements. At the other extreme there are those who foresee a relatively smooth transition

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bore whole. Not to confuse with shale oil is oil shale, which is a different material, a predecessor to oil, rich in organic matter called Kerogen. To convert it into oil it needs to be strip mined and cooked.

(in German “Energiewende”) to a future of no energy scarcities (and hardly any need for frugality or systemic adaptation) due to efficiency improvements (e.g. von Weizsäcker, Lovins et al. 1997) and advances in alternative technologies (e.g. Cleveland 1991; Klare 2002; Rifkin 2002; Brandt 2007; Kilian 2008; Fath 2012). To some of the latter optimists Peak-Oil is merely a “recurring myth” (Caveny 2006) or a “catastrophic cult” (Smil 2006).

Similarly, in the second group of political scientists some could be regarded as pessimistic, because they predict an intensification of conflicts and wars over resources (e.g. Holling and Gunderson 2002; Goodstein 2005; Elsayed and Elrefaai 2008; Campbell 2009). Others, on the other hand, believe that Peak-Oil is ‘socially constructed’ by oil producers and oil companies, in order for them to justify the exorbitantly high oil prices (e.g.: Bridge 2010).

In the third group of economists, one can quite clearly speak of two different paradigms, which affect how Peak-Oil is being interpreted. The economic mainstream mostly subscribes to unquestioned technological optimism (see Part 3), which justifies the paradigmatic assumption of unlimited substitution possibilities and the relative scarcity of all resources. This means that one resource is only scarce relative to another resource, or the same resource but of a different (lower) quality. Relative scarcity can be overcome by substitution, whereby relatively scarce resources are eventually substituted by relatively abundant ones. Resources are therefore unlimited in total and merely non-homogenous in quality. The price mechanism will automatically make consumption switch from the scarcer resource to an alternative i.e. the so-called Hotelling’s Rule of ‘substitutability’(Bradford 2006) or Nordhaus et al.’s ‘backstop technology’(Nordhaus, Houthakker et al. 1973). This line of reasoning is still dominant in mainstream economic theory (e.g. Barnett and Morse 1963; Solow 1974; Lenssen and Flavin 1996; Adelman and Lynch 1997; Lynch 1999; Odell 1999; Hisschemoller, Bode et al. 2006; Jackson 2006; Maack and Skulason 2006). Without absolute resource scarcity, Peak-Oil may or may not occur soon, but won’t have much effect on world economies.

According to ecological or biophysical economists, whose arguments are mostly based on the laws of thermodynamics, *ultimate means* in the form of low entropy matter/energy are scarce in an *absolute* sense i.e. there are absolute limits beyond which availability is nil (e.g.: Georgescu-Roegen 1971; Meadows, Randers et al. 2004; Victor 2008). This very distinct argumentation compared to that of the mainstream, has rather significant implications for policy recommendations in relation to most sustainability challenges and the governance of natural resources (both renewable as well as non-renewable). Historically one could say that in the 1970ies and early 1980ies these concerns about limits were expressed in terms of "depletion" of stocks of non-renewable resources (low entropy) (Georgescu-Roegen 1971; Meadows, Meadows et al. 1972; Daly 1973; Schumacher 1973). Since the turn of the century, depletion is slowly being replaced by the concept of "resource peaks" (e.g. Daly 2010). It has become evident that non-renewable resources are both stock *and* flow limited (Kerschner, Bermejo et al. 2010) (see Chapter 2.1.6) – a fact which moves resource scarcity issues suddenly much closer.

Technological optimism could be seen as the main source behind the general optimism concerning resource peaks of all three before mentioned groups (natural and political scientists and economists). What follows from fully subscribing to this attitude towards technology (see Part 3), is to direct all policy attention to fostering research and development of new technologies, ideally by relying on the 'creative powers' of free markets. Policy recommendations from pessimists are less unified and more complex. Some argue in favour of a conscious downscaling (degrowth) of the economy i.e. "slower by design not disaster" towards as steady state economy (Odum and Odum 2001; Kerschner 2006; Victor 2008; Jackson 2009; Kerschner 2010; Martinez-Alier, Pascual et al. 2010) (see Part 4). The correct response to Peak-Oil according to these authors is therefore (apart from fostering sustainable technologies) to plan and design a smooth decent or transition from the top of the Hubberts peak, rather than "squandering" by trying to climb up further followed by a painful collapse.

Others object to such proposals, arguing too little is known still about the functioning of our economic and energy system. Any unwise tinkering with the cogwheels of the clockwork economy, may lead to an even more painful standstill and collapse, then if it was left alone. The only thing we can do for now is trying to better understand our energy-economy system (Polimeni, Mayumi et al. 2008; Hall and Klitgaard 2011; Helman 2011; Healy 2012; Sorman and Giampietro in press), in order create a knowledgeable position from which one could attempt to consciously adapt to the declining resource base.

Given the above positions, the leitmotif for this PhD thesis could be summarized as follows:

(1) Because of the available evidence there is significant risk of Peak-Oil having occurred already or going to occur very soon. Some of this evidence will be touched upon

throughout this document. The following chapter is an attempt to summarize some of the main arguments brought forward in for and against the likelihood of an imminent energy crunch. The main purpose of that chapter is to categorize the factors contributing to Peak-Oil into that of quantity and quality (Kerschner, Bermejo et al. 2010) and to emphasize that Peak-Oil is not only a stock problem (i.e. remaining recoverable resources in the ground – the size of "the barrel") but also (and most importantly) a flow problem (i.e. producing enough oil per unit of time – the size of "the tap").

(2) Efficiency improvements and new technologies will be important for the therefore necessary transition to a low-carbon economy. However our economic system is also an energy system based on cheap oil. Substitution of oil in the quantities (daily flow rates) and qualities (low costs) needed, is difficult due to the special properties of that energy resource until now (e.g. high net energy content, easily transportable, relatively cheap to extract and process, enormous deposits etc.) (see also the following Chapter) (Kerschner and Arto-Oliazola 2011). In other words this refers back to the previous argument about absolute scarcity: Oil, in the quantity and quality we need, is scarce in an absolute sense.

(3) Another fact which illustrates this absolute scarcity and difficulty of substituting key resources, is that a number of other resources may also be scarce and reaching resource peaks e.g. The scientific and popular literature now talks of Peak-Coal (e.g.: Zittel and Schindler 2006), Peak-Phosphorus (Cordell, Drangert et al. 2009; Taylor 2009), Peak-Uranium (Zittel and Schindler 2006; Smil 2008; Lin and Liu 2010), Peak-Minerals (Bardi and Pagani 2007; GAO 2007), Peak-Water (Kilian 2008; Vivoda 2009), …, Peak-Everything (Heinberg 2007). Two of the above will be given a closer look: Peak-Coal (Chapter 2.3.1) (Kerschner, Bermejo et al. 2010) and Peak-Phosphorous (Chapter 2.3.2) (Cordell and Kerschner 2007).

(4) For the above reasons we urgently need to set in place contingency plans and put in place measures for a smooth adaptation process. A precondition for this is enhancing our knowledge about the nexus between our economy and its principal sources of energy. Among other things we need to identify the most vulnerable economic sectors, in order for supporting them, fazing them out completely or replacing them with other less vulnerable sectors (see Part 2). The concepts of resilience, vulnerability, adaptability and transformability (Chapter 3.3), are essential for defining this first step for the initiating a process of adaptive resource management.

(5) Chapter 2.4 will look into the question of why the issue of resource peaks is not addressed already in the appropriate arenas (Cordell and Kerschner 2007). A fist conclusion of this institutional analysis is that the main institutions in charge for the governance of key non-renewable resources are not organisations such as the IEA (International Energy Agency) but markets. Free markets for governing non-renewable resources on the other hand are justified by the before-mentioned relative scarcity and technological optimism in neoclassical economic theory. Only under these preconditions can these resources be valued, because there are no issues of intergenerational resource distribution.

(6) Since technological optimism seems to be one of the main obstacles behind an appropriate institutional response, it would be of great scientific interest to investigate the general issue of attitudes towards technology in sustainability sciences. For this purpose an analytical framework (the ATT-framework) is reproduced (Ehlers and Kerschner 2010) in Part 3 as well as the results of an online survey at an international conference of Ecological Economists (Ehlers and Kerschner submitted). The goal of this research is to create a critical, reflexive debate, about the justifications behind the paradigmatic dominance of unquestioned optimism in modern western societies.

(7) In the last part (Part 5), I am discussing the radical policy objective of creating a steady state economy as proposed by Daly (1973) as the only path towards sustainability (Kerschner 2006). Since our economic system is most certainly already overshooting in many ways (Jevons 1924; Giarratani and Hydock 1978), this requires conscious downscaling (degrowth) of most over-consuming industrialized countries (Kerschner 2010).

Hence the main goal of this study is not to enter the discussion of when Peak-Oil is going to occur;. it is about enhancing our knowledge for introducing adaptation policies, in order to avoid an uncontrollable, painful collapse of our economic system. Even though Peak-Oil will be a new experience, history provides some examples of the possible economic, political and social impacts of similar phenomena, which is likely to vary depending on the country or region (Friedrichs 2010).

When in the early 1990s the iron curtain fell in Europe and the Soviet Union started to disintegrate, one of the third party countries most affected was Cuba. Not only did it lose 85 per cent of its trade, but also did it see its subsidised oil imports from the former USSR halved. During, what is known to Cubans as, the "Special Period", their economy entered a free fall with GDP dropping by 30%. The average Cuban is said to have lost about 15 kilograms in body weight (Quinn 2006). However, because of a remarkable socioeconomic adaptation process (Friedrichs 2010), Cuba survived its special period. Since then the country has recovered slightly, which was only possible by drastic measures to save energy consumption and by wider opening its borders to Western tourists. Much worse were the impacts of the sudden interruption of subsidised USSR oil flows for the people of North Korea - between 600.000 to 1 million died in a famine caused by a complete disintegration of their economy (Friedrichs 2010). These examples illustrate firstly the danger of oil supply shocks and secondly how adequate preconditions and pro-active policies for reducing an economy's vulnerability by fostering its innovative adaptability and transformability can help to avoid human tragedies (e.g. Quinn 2006).

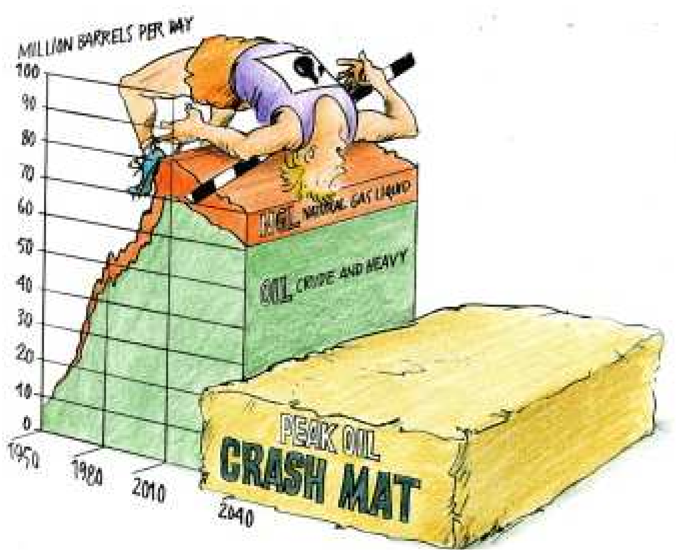


Figure 1: Adaptive resource management, or creating a Peak-Oil crash mat.
Source: Peaking at Peak Oil Hamilton (2005), Drawing: Olle Qvennerstedt

2 Peak-Oil

2.1 Introduction – "quality and quantity"

2.1.1 Depletion vs. Resource Peaks

Modern industrialized economies are highly dependent on a variety of non-renewable resources. The scarcity and depletion of some of them had already been a major subject of concern for thinkers and economist in the past such as was fertile land for Malthus (1798) or coal for Jevons (1865). These considerations were dismissed by the next generation of economists when the potentials of petroleum became evident and when it facilitated the emergence of the “green revolution” and modern agriculture. It would take until the 1970ies with its two consecutive oil-shocks and the publication of “The entropy law and the economic process” (Georgescu-Roegen 1971) and “The limits to growth” (Meadows, Meadows et al. 1972) for the debate to awaken again.

2.1.2 Peak-Oil vs. depletion

Today the depletion of certain key resources within one person’s lifetime is no longer a subject of doom-mongers. BP in its influential statistical review of energy for example estimates proved oil reserves to run out in 42 years and gas reserves in 60,4 years at current consumption (BP 2009). Nevertheless regarding Jevons´ (1866 [1865]) fear of an imminent depletion of coal, the same report assures us that at current consumption this is still 122 years away (BP 2009). On the European Union’s Energy Portal, we are even given a date and a time for the exhaustion of oil (20:58 Oct 22, 2047), gas (09:25 Sep 12, 2068) and coal (23:12 Nov 28, 2144) at given consumption (EU 2010). This indicator i.e. proved recoverable resources (R) divided by present annual production (P), may be illustrative and easy to communicate, but at the same time it is utterly meaningless and misleading for the problems we are facing.

The critical moment for human society is not when the last drop of *economically extractable* oil or the last piece of *recoverable* coal will be depleted.[3] Instead, the critical point is that of maximum or peak production, because this is when we are suddenly facing a “regime change” in our energy system (compare Odum 1971; Brown, Cohen et al. 2009), which for the last century has conditioned all aspects of our society, including our economic system. The cornerstones of this energy system are resources, which are accessible to us in a certain *quality* and *quantity* (stock and flow). Regarding quality we can say that generally the best deposits are always exploited first i.e. the best first principle going back to David Ricardo (1821). Hence the characteristics of the second half of our endowment are less favourable:

[3] The first common misunderstanding when talking about the depletion of non-renewable resources is that it is assumed that ALL of the existing resource on the planet can be extracted. Hundred percent recovery of most resources is physically and economically impossible (Bardi and Pagani 2007; BP 2008). For a series of geological reasons a large part of the resource remains inaccessible or too expensive to extract. However in the case of coal even geologists for a long time used field measurements of bore holes to determine the amount of coal available, which is the data behind the often quoted 250 years’ worth of remaining coal in the US (Kerr 2009).

lower concentration and/or purity (e.g. heavier oils or larger fraction of contaminants like sulphur) and geologically and/or politically less accessible. So we can distinguish between the quality of the resource in the ground and the quality of the site of the deposit. These factors reduce the net energy content (energy output – energy input) of the final product or its EROI (Energy Return On Investment)(Hall and Klitgaard 2011). Same is true for the site-quantity factor, namely the fact that new discoveries tend to be smaller deposits, which increases exploration and exploitation costs per recovered unit of resource. The discovery of giant oil fields (i.e. above 0.5 Gigabarrels), which account for only about 1% of all the world's oil fields, but for about 60% (Robelius 2007) of world production, is very rare these days.

2.1.3 The hype and problems about recent discoveries: conditions at the commodity frontiers

Brazil's "Tupi" deep-water field of 2006 and Ecuador's Yasuni-ITT are such rare examples, which tend to create a lot of media attention, and the perception that there is still plenty of oil to find. Although the quality of Tupi's resource (light-medium sweet crude oil) is not bad,[4] the quality of the site is highly problematic as it lies 300 kilometres off shore in a depth of 5-7 kilometres (2 km of seawater, 1 km post-salt and 2 km of salt)[5]. From the site-quantity point of view Tupi apparently was the largest find since 30 years (Wikipedia 2010b). However even at the most optimistic levels of ultimately recoverable oil (8 Gb), it would only provide 3 months of world oil demand at 2008 levels (85 million barrels daily).[6] The controversial Ecuadorian Yasuni-ITT field (also giant), which lies within a natural park of exceptional beauty and biodiversity, would provide less than 11 days of world oil demand, if its estimated 0.9 Gb (www.yasuni-itt.gov.ec) of heavy oil were to be exploited. As we will see below, though fairly large, it is assumed that what is actually needed after Peak-Oil are discoveries with the daily oil production capacity of (10.85 Mb) of deposits in Saudi Arabia (264.2 Gb) (BP 2009) every two (Bermejo 2008) or three years (Sorrell, Speirs et al. 2009).

[4] The most sought after oil is "light sweet crude oil", where "light" refers to its gravity relative to water measured in API (American Petroleum Institute, if higher than 10 then it floats on water) and "sweet" to its low sulfur content. Light sweet crude has an API higher than 31.1 ° (less than 870 kg/m^3) and a sulfur content of less than 0.5%. In Energetic terms, when comparing light sweet crude with "extra heavy sour", we can talk from two completely different types of energy resources – the latter having a net-energy content closer to coal than to the former.

[5] Especially the salt-layer poses extreme technical challenges. See the "tupi-challenge" animation from Petrobras at http://www2.petrobras.com.br/ri/ing/DestaquesOperacionais/ExploracaoProducao/CampoTupi.html

[6] The Association for the Study of Peak Oil (ASPO), puts its estimate at less than half that, between 1.4 and 3.6 Gigabarrels (Gb) of recoverable oil (ASPO 2008).

The last argument adds an ethical and environmental dimension to the point of site quality, given that more and more exploration and extraction takes place in ever remoter regions, right at the commodity frontiers as defined by Marinez-Alier (2002). Extractive activities carried out in these regions can be disastrous for the environment and the people living in its vicinity (see for example: Orta Martínez, Napolitano et al. 2007). In 2010 the world was painfully reminded of this fact (Healy 2012), when as much as 70.000 barrels (consumption of Slovakia) of crude oil may have been leaking into the Gulf of Mexico (Gail the Actuary 2010) daily.

To recapitulate, we can say that oil is not equal to oil, when comparing the quality of the resource (light sweet vs. heavy sour), the quality of the sites and the quantity found per deposit. In terms of net energy one may say that, most of the oil remaining and discovered today is in fact a different source of energy, which is the first reason why the above mentioned ratio R/P is meaningless. In fact the distinction made between conventional and non-conventional oil does reflect these differences in the quality of the resource very well.

2.1.4 Unconventional Oil

Unconventional oil includes heavy oils, like Canadian tar sands, shale oil and gas, oil shale, polar and deep-water (> 500m) oil. Very often, NGL's are also included, which are light hydrocarbons that exist in liquid form underground and that are produced together with natural gas and recovered in separation facilities or processing plants e.g. propane and butane. At this moment only NGL, Canadian tar sands deep-water sources and since the development of 'fracking technology' shale oil and gas are relevant factors for liquid fuel provision and according to ASPO together they prevented oil production to peak early in 2005 (ASPO 2009). NGL obviously has its own markets, uses i.e. mainly for heat and electricity production and supply problems. Deep-water offshore oil is currently producing 7 Mb/d, but it appears unlikely that this can be increased in the future because of a rapid decline of mature wells ("ace" Eriksen 2009). Nevertheless the unconventional oil and gas are often the source of great optimism regarding future oil supplies for some (Glover and Economides 2012; Maugeri 2012) (see Figure 2 below).

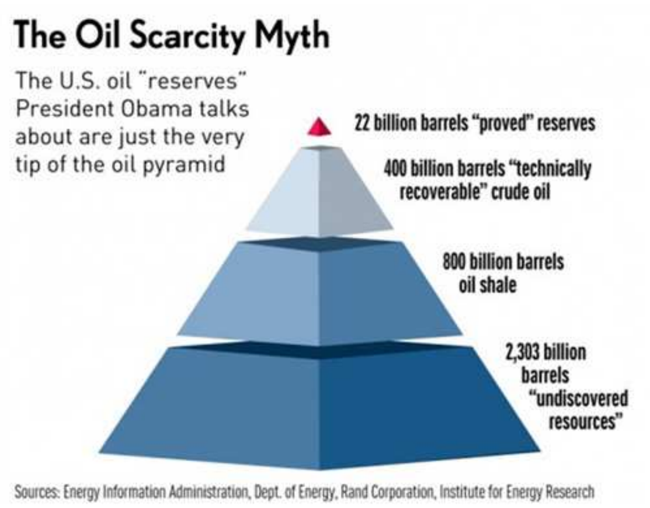


Figure 2: Optimistic outlook of future oil supply
Source: http://www.energytribune.com/articles.cfm/10132/Iran-and-the-Oil-Scarcity-Myth

2.1.5 Canadian tar sands

Canada currently produces 1.32 Mb/d from their tar sands, which officials hope to raise to 3 Mb/d until 2018[7]. This contribution to world oil production (WOP), which is around 85 million barrels per day (Mb/d) is rather modest, given the fact that Albertans are supposedly sitting on 170.4 Gb (Government of Alberta 2010) of crude oil equivalent (proved reserves). This huge deposit led some to claim that Canada would be the future Saudi Arabia, which currently has proven reserves of 264.2 Gb (BP 2009). However extracting oil from open pit tar sand mines has nothing to do with pumping oil from a well in the Middle East. Firstly because the net energy obtained is much lower. Trying to include all direct and indirect factors into an energy balance is a tricky and still a heavily debated issue (Giampietro, Mayumi et al. 2010), but so far EROI (Energy Return on Investment) studies by Charles Hall and others (e.g. Murphy and Hall 2010; Hall and Klitgaard 2011) suggest that oil from tar sands have an EROI of between 2-4 units of energy output per one unit of input, compared to oil and gas which was produced in 1970 with around 30:1 and that of 2005 which lies in between 11-18:1. Shale oil[8] is estimated at around 5:1, but according to some (Brown 2006) it will never be a viable source of energy. The financial crises of 2008 provided evidence for the downsides of a low net energy content, as the Albertan economy suffered a huge blow, when oil prices sank and investors shied away from expensive tar sand projects (Economist 2009). Secondly the social and environmental costs of processing tar sands (and other

7 Source: http://www.energy.gov.ab.ca/OurBusiness/oilsands.asp
8 For an explanation of the essential difference between shale oil and gas and oil shale see Footnote 2 in Chapter 1.1.

unconventional oil), are enormous, producing conflicts with indigenous population and contaminating huge areas with toxic materials. 530 km², almost the size of Singapore, of so far untouched Albertan forests and wetlands have been stripped already by the four mayor mining companies (Kean 2009). Similar problems and limitations are emerging regarding most other unconventional sources of oil and gas e.g. deep water (Healy 2012) or shale oil and gas (Jones, Leiby et al. 2004; Simmons 2005; Mearns 2012; Reuters 2012; LBST unpublished, 2010) which had motivated the IEA to herald the start of a 'golden age of gas'(IEA 2012).

2.1.6 Peak-Oil: both a stock and a flow problem

The case of Canadian tar sands shows already very well the implications of the second reason why the above mentioned R/P ratio is misleading. This is the often forgotten time-dimension of resource quantity i.e. the extraction flow rate. While we may be aware that renewable energy resources like solar radiation are super abundant but flow limited (Georgescu-Roegen 1971), it is less known that the production of energy from our terrestrial stocks also becomes flow limited once all wells or mines reach a maximum geological and economical level of production per unit of time. In the case of petroleum, the phenomenon of both a stock and a flow limitation, is today referred to as *Peak-Oil*[9] and has first been described by petroleum geologist King Hubbert (1949). In terms of Alekletts Figure 3 below, it is both the size of the barrel (URR see below) as well as the size of the tap that determine the phenomenon of Peak-Oil.

Figure 3: Peak-Oil – size of the Barrel and size of the tap
Source: Peaking at Peak Oil Hamilton (2005), Drawing: Olle Qvennerstedt

[9] Hubbert did not invent the term Peak-Oil, this was done by Campbell and Aleklett in 2001 - see footnote number 1 of Chapter 1.1.

Hubbert (1949; 1956) argued that production peaks in the form of bell shaped curves that could be observed for individual oil fields, would eventually occur for entire oil regions, countries and eventually the world. These production peaks and the shape of the curve could be predicted mirroring the discovery peak curve. In the US discovery had peaked in the 1930ies, which allowed Hubbert (1956) to predict the US peak for the lower 48 States for 1971[10], being only one year off the actual peak in October 1970 (USGS 2008). His methods have been refined and complemented with new available data by ASPO (Association for the Study of Peak-Oil and Gas), which produced Figure 4, showing global Peak-Oil at around 2010, and a decline of oil production thereafter. Nevertheless there are authors which criticise Hubbert's method and argue that even his often recounted successful prediction of the US Peak was mere fluke (Kaufmann 2006). A detailed evaluation of all methods for determining resource peaks and applications so far has been presented by Sorrell and Speirs (2009). The authors conclude, that there was enough credible evidence that a global production peak of conventional oil before 2030 was likely (for below ground rather than above ground reasons) and that there was a significant risk for this to occur before 2020. Un-conventional oil has not been taken into account in the report, but it is argued that it won't be able to fully compensate an expected decline rate of about 4% annually.

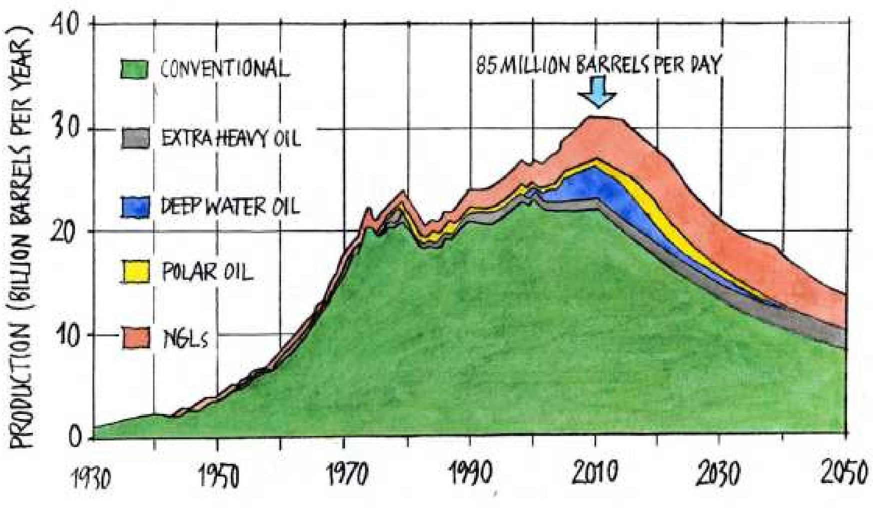


Figure 4: General oil and gas depletion picture
Source: Peaking at Peak Oil, Hamilton (2005), Drawing: Olle Qvennerstedt

2.1.6.1 Ultimately Recoverable Resource –the stock-quantity dimension of Peak-Oil

Apart from the already mentioned flow-quantity dimension the other key variable for determining global Peak-Oil is the global stock quantity measured as Ultimately Recoverable

[10] „hubbert's peak"

Resource (URR)[11]. Both variables are crucial for modelling production curves like the one above (Figure 4) and the corresponding resource peaks with curve fitting and other methods. The heavy debates among those trying to predict the exact timing of the peak are basically about the magnitude of these figures. For Figure 4 ASPO puts global URR at 1900 Gb for conventional oil and at 2425 Gboe (Gb of oil equivalent) for *all liquids*[12] (including non-conventional oil and NGL). The US geological survey (USGS) on the other hand continues to insist on a URR of conventional oil of 3021 Gb (USGS 2000) and at least the same amount of unconventional oil. However this data includes a large part (732 Gb) of future discoveries, which is only a quarter of the actual discovery trend at the moment and an equally large part of *reserve growth* (688 Gb). The latter is an indicator reflecting expected improvements in the recoverability of oil from existing fields (see Figure 5 for an overview of estimates for URR according to different studies). The importance of URR figures has also been illustrated by the most extensive meta-analysis of Peak-Oil studies so far, the 2009 Report by the UK Energy Research Centre (Sorrell, Speirs et al. 2009). Figure 6 shows how estimates for Peak-Oil varies between 2001 and 2034 depending on the underlying assumption for URR (conventional only).

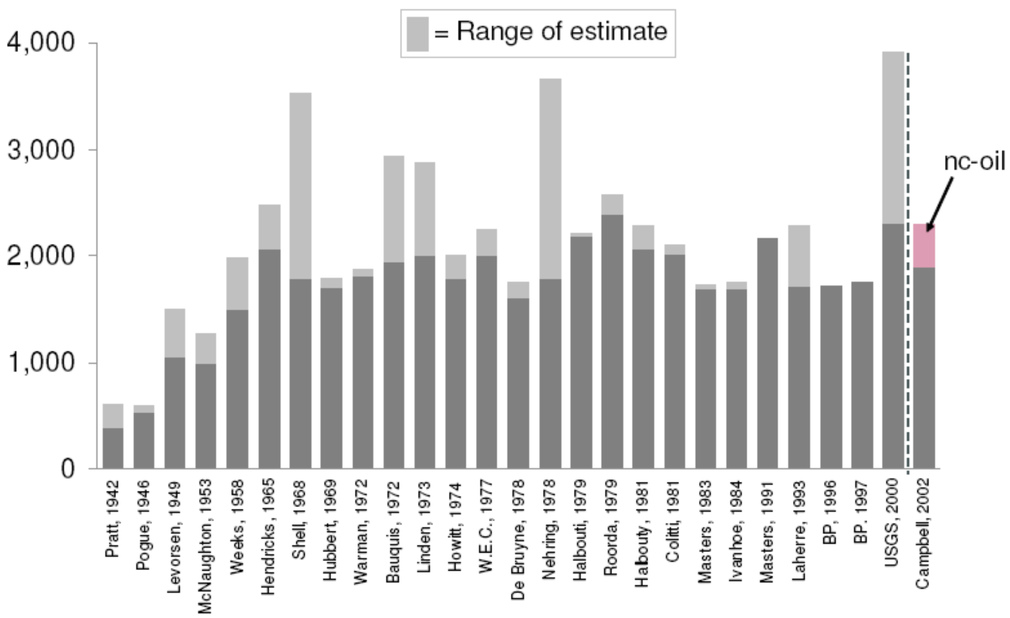


Figure 5: Estimates of URR for oil (dark gray is proved reserves)
Source: Zittel and Schindler, 2008, p. 37

[11] Terminology is very important when talking about oil reserves. Ultimately recoverable reserves (URR) also referred to as Total Recoverable Reserves, Ultimately Recoverable Reserves, "Ultimate" or Estimated Ultimate Recovery (EUR used by BGR-Germany) is the total amount of recoverable resource in the ground before production starts (ASPO) or in simpler terms the total quantity of a given resource that will ever be exploited. So for oil, per definition URR includes oil consumed already, oil consumed in the future from existing wells and from those which are expected to be discovered still.
[12] All fuel liquids include conventional and non-conventional oil and biofuels.

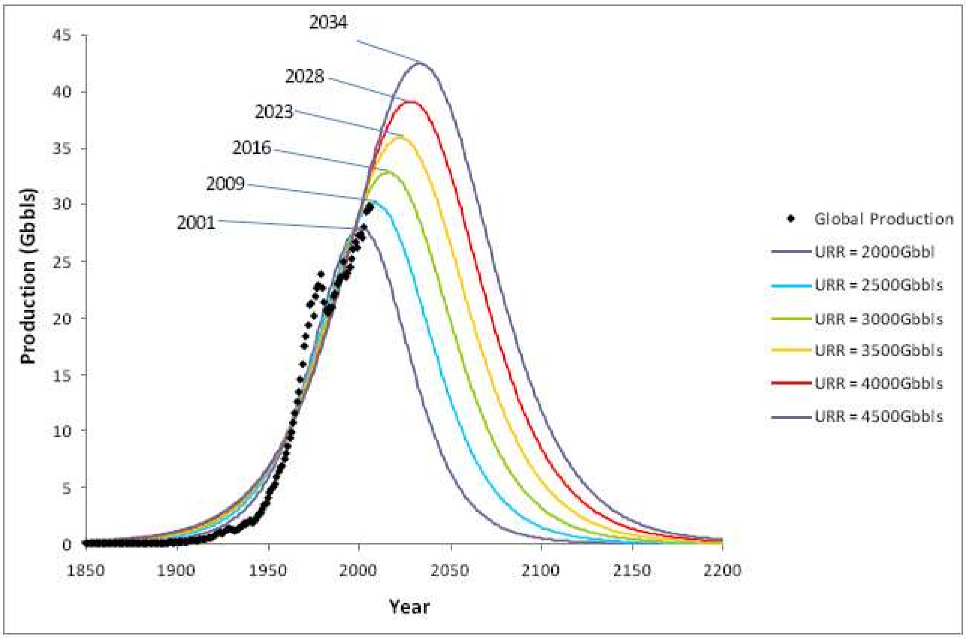


Figure 6: The peaking of global conventional oil production under different assumptions about the global URR - simple logistic model
Source: UKERC Technical Report 5 (Sorrell and Speirs 2009, p 179)

This large diversion of URR estimates are due to several factors, probably the most important one being predictions for reserve growth. This factor leaves room for a lot of technological optimism, since an increase of only 1% of the world's average recoverability rate, would provide the equivalent of all the oil in the North Sea. The absolute limit for recoverability for an energy resource is the breakeven point of energy invested to energy gained (when net energy is zero), which can of course be postponed by technological innovation. However thermodynamics poses ultimate limits and history has shown that advances in extractive technology so far have merely helped to increase the speed of extraction (hence leading to a faster depletion of the resource) not the recoverability rate (www.simmonsco-intl.com). After almost a century of oil extraction conventional petroleum fields for example still only tend to have an average recovery rate of around 35% (Leggett 2006, p. 67).

However even if the URR is very large for a deposit, like for the above mentioned Brazilian Tupi field or the Canadian tar sands, this number on its own is meaningless for economic purposes, without knowing the amount which can be extracted from these deposits on a daily basis (the flow-quantity). There are many geological, geopolitical, technical, environmental, economic and social reasons why production flow rates have upper limits, which are difficult to foresee. For Canadian tar sands it may be the environmental destructiveness and investment intensity of the mining operation, while for the Tupi field it could be the fact that it is not an underground lake of oil, but, as many deposits nowadays, a special type of rock which is impregnated with the oil. If the flow rate cannot be increased anymore but if the URR is sufficiently large, we could see a peak plateau rather than a sudden peak like in the figures above. Many argue for example that coal extraction, because of its specific properties, is likely to reach a long plateau (Kerr 2009). It is a highly complex matter to predict the timing and level of the peak of oil production but a large group of experts claim that we have passed peak production around 2010 at about 85 Mb/d (Figure 4). A different scenario by the Energy Watch Group (Zittel and Schindler 2008) argues that Peak-Oil has already occurred in 2006 at 81 Mb/d. (see Figure 7 below). There are still some doubts about if this could be a peak or more like a peak plateau for some time, due to demand destruction during the 2008 world crisis and slightly higher potentials of unconventional sources than expected (Kerschner 2012). Dittmar (2011) of the Uppsala group calculated world oil production scenario forecasts according to BP data. Figure 8 shows how actual production is even below the worst case scenario until now: 82.2 Mb/d in 2007; 82.8 Mb/d in 2008; 81.3 Mb/d in 2009 and 83.2 Mb/d in 2010 (IEA data).

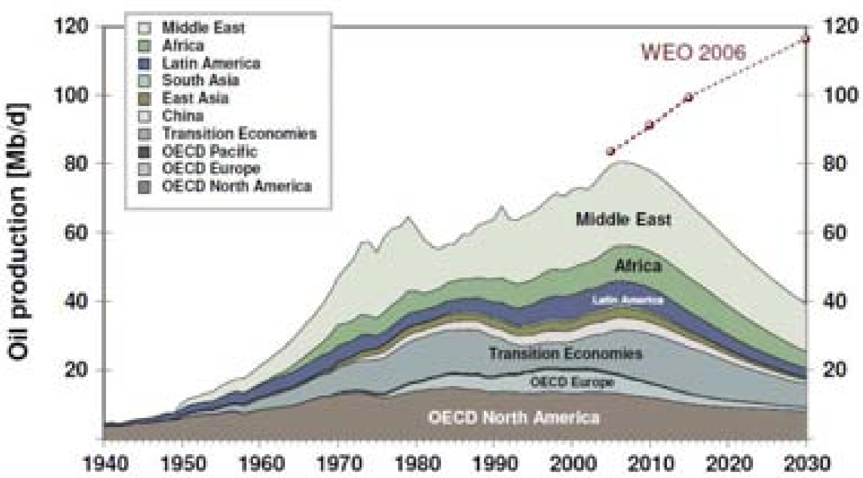


Figure 7: World oil production summary scenario by regions.
Source: Crude oil the supply outlook Zittel and Schindler (2008), Figure 40, p. 70

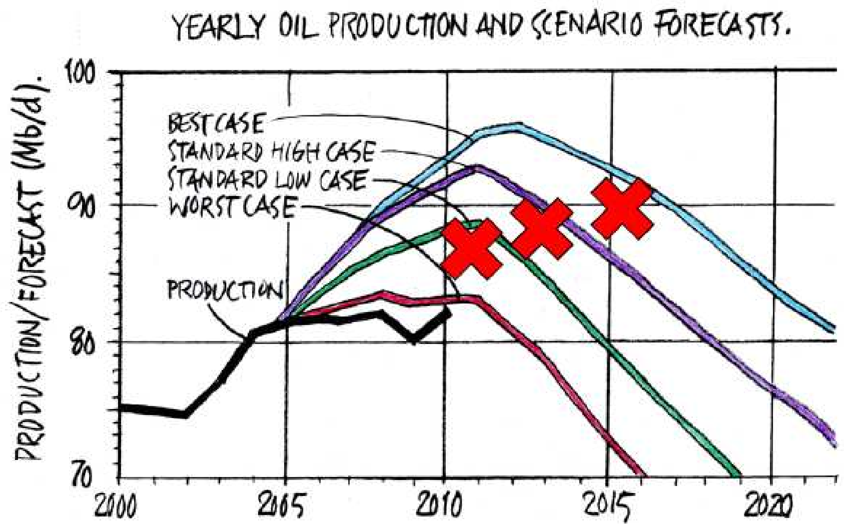


Figure 8: Yearly oil production and scenario forecasts according to BP data
Source: Giant Oilfields - The Highway to Oil (Dittmar 2011), Drawing: Olle Qvennerstedt

Looking only at IEA forecasts for already producing fields, we see a similar scenario as the one offered above (see Figure 9). However the organization assumes that this decline will be more than compensated by 'yet to be developed' and 'yet to be found' oil fields plus NGLs, unconventional oil etc. These estimates are extremely optimistic as it is not known where those extra fields are to be found and if unconventional fuels have such great potentials (Aleklett, Höök et al. 2010).

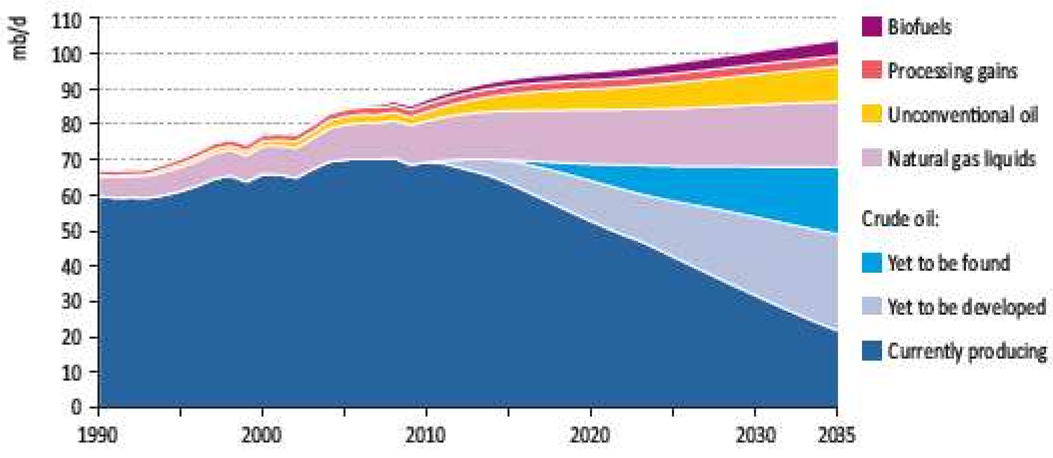


Figure 9: World liquids supply by type in the IEA New Policies Scenario
Source: IEA WEO (2011)

2.1.7 Potential effects of resource peaks: Peak-Oil and the financial crises

A peak plateau is of course less damaging than a sharp peak, but as mentioned earlier our world economic system is built upon the constant increase of resource consumption in general and energy consumption in particular. The economic effects of Peak Oil and other resources will depend to a large extent on the decline rates of existing wells. Estimates about decline rates vary greatly depending on the source (Bermejo 2008): 4.7% (Skrebowski 2008); ~4% (Sorrell and Speirs 2009), 6.7% (IEA), 6.8% (National Petroleum Council), etc. But there is considerable agreement among experts, that the rate will be at around 5% (Nelder 2008). Applying this rate of decline to the production rate of 85 Mb/d, which were reached in 2008, means that oil fields need to be discovered which contribute 4.25 Mb/d in order to maintain supply. Adding an estimated average increase of oil demand of 1.5% per year this means additional 1.2Mb/d or a rounded total of 5.5 Mb/d. This would mean the discovery of new fields with the daily supply potential of all of Saudi Arabia every two years (Bermejo 2008). Figure 10 below, demonstrates the growing gap between production and new discoveries.

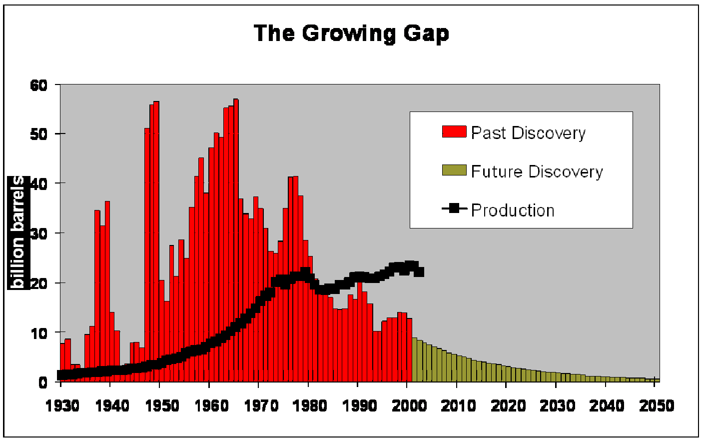


Figure 10: The growing gap between global oil production and expected new discoveries
Source: Skrebowski ASPO USA (2008)

While there is a lot of debate and research going on to answer the question of "when" Peak-Oil will happen, very few studies exist still, which ask what it could mean for our world economic system (exceptions include Arto-Oliazola and Kerschner 2009; Kerschner and Hubacek 2009; Friedrichs 2010; Logar and van den Bergh 2011; Lutz, Lehr et al. 2012). Most certainly the imminent reaction would be a sharp increase in energy prices like the ones we saw in 2008, when oil climbed to just over 140 dollars per barrel. Such an increase of expenditures is highly damaging to economic growth and the international financial system, which is built on debt against the hope of future expansion (Douthwaite this issue). Although this is difficult to prove, there seems be a growing consciousness that the 2008 financial crises as caused by the explosion of oil prices (Hamilton 2009; Kaufmann, Gonzalez et al. 2010), which ASPO representatives like Colin Campbell in turn attribute to the attainment of the Peak (Murphy and Balogh 2009; Theramus 2009; Lewis 2010; Lewis 2010; Chanel 2012). Figure 11 provides some evidence for this hypothesis, indicating that all oil price spikes in the U.S. tend to be accompanied by periods of recession (Murphy and Balogh 2009). In addition, some believe that the current recession in many OECD countries and the EURO-crises are directly or indirectly caused by overheated and volatile oil markets (Hagens 2008; Stern 2010; Tverberg 2010; Skrebowski 2011; Li 2012). Leaning from history is naturally difficult for the case of Peak-Oil, because a similar event has not occurred before (except maybe for isolated cases such as Cuba and North Korea in the 1990ies). Nevertheless some more insights into the potential macroeconomic impacts of oil supply shortages – mostly via escalating fuel prices as in Figure 11 - can be gained from looking at past oil shocks.

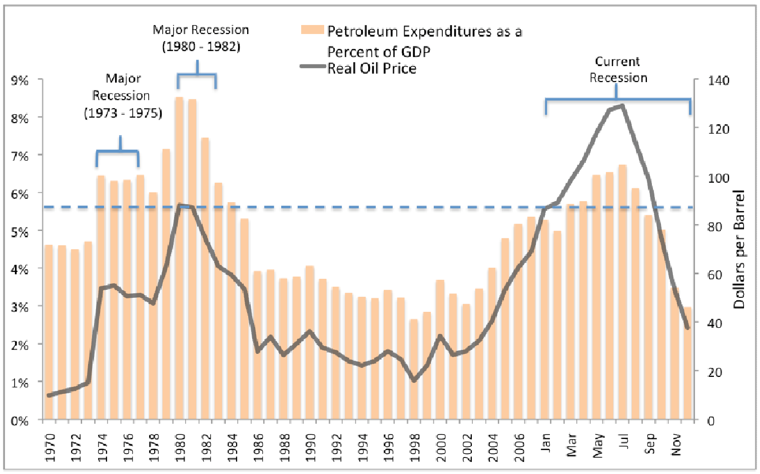


Figure 11: Petroleum expenditures as a percentage of U.S. GDP and real oil prices
Source: Murphy and Balogh 2009

2.2 A brief history of oil supply shocks

Oil shocks are significant oil price increases due to a substantial decrease in world oil supply. These events are usually a direct cause of geopolitical developments mainly within Middle Eastern countries and thus are exogenous to other economies in the world. In other words individual economies can be seen as price takers for crude oil (Lee, Blakeslee et al. 1977). Historically four oil shocks can be specified. The first of these occurred 1956, caused by the Suez Crisis. In October of that year Israeli troops, and subsequently the French and British military, invaded Egypt's Sinai Peninsula. Oil tankers were prevented from using the Suez Canal, a major route for crude oil transport (1.2 million barrels a day at that time). In addition the Iraq-Syria pipeline was sabotaged, which had been carrying another half a million barrels a day and on top of that Britain and France were boycotted from receiving oil from the Middle East altogether. The combination of these events resulted in a drop of 10.1% in world oil production (WOP), the largest such relative drop among all four oil shocks. In October 1973, the Organization of Arab Petroleum Exporting Countries imposed an embargo on countries, which were perceived to support Israel in its military conflict with Syria and Egypt. WOP only declined 7.8%, but oil prices almost quadrupled within just three months, from US$ 3.01 per barrel in mid-October to US$ 11.65 in January (Hamilton 2003; 2011).

The third large oil shock was caused by the Iranian revolution, as the country's oil production fell from 6.1 million barrels a day (Mb/d) in September 1978 to a mere 0.7 Mb/d in January 1979 - the equivalent of 8.9% in WOP. Exacerbated by widespread panic, oil prices more than doubled to their highest nominal level until early 2003: US$ 39.50 per barrel. Iranian oil production had hardly recovered, when in October 1980 the country became embroiled in a military conflict with Iraq, resulting in a virtual standstill of its own and a dramatic drop of Iraqi oil production – WOP dropped yet again by 7.2%. Finally, the most recent military conflict affecting oil markets, erupted when Iraq invaded Kuwait in July 1990, with later US intervention in what is known as the Persian Gulf War. Together Iraq and Kuwait produced 5.3 mbd, which came to a complete halt during the conflict, meaning a shortfall of 8.8% of WOP. Table (1) below provides an overview of Oil supply reductions and price increases.

Date	**Event**	**World Oil production (Mb/d)**			**Oil prices (nominal US$/barrel)**		
		before	**after**	**%**	**before**	**shock**	**%**
Nov. 1956	Suez crisis	16.8	15.1	-10.1	1.93	-	-
Nov. 1973	Arab-Israel war	55.7	51.3	-7.8	3.01	11.65	+287
Nov. 1978	Iran. revolution	60.2	54.8	-8,9	15.85*	39.5**	+40
Oct. 1980	Iran-Iraq war	59.6	55.3	-7.2	-	-	-
Aug. 1990	Persian Gulf war	60.5	55.1	-8.8	-	-	-
March 2005	weak dollar	-	-	-	-	58.28	-
Summer 05	Hurricane Katrina	-	-	-	-	>60	-
Winter 05/06	Nigeria / Iran	-	-	-	-	66.3	-
April 2006	Nigeria / Iran		-	-	-	75.35	-

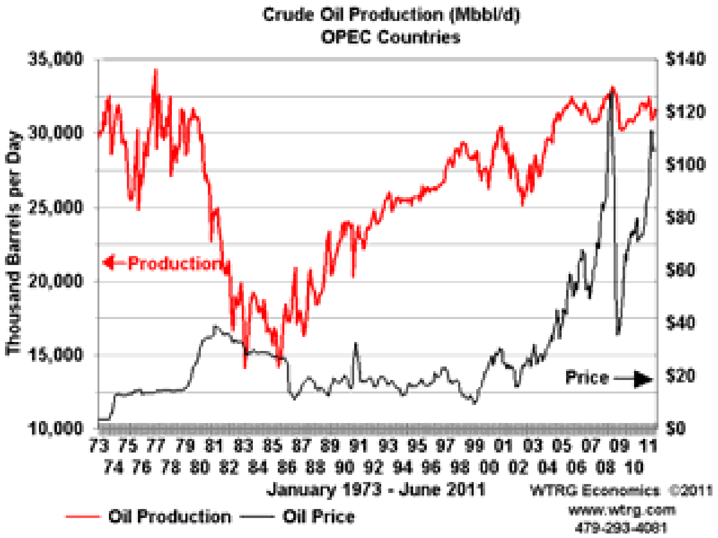
*US price, Subject to price controls until April 1979

** US price, after the Carter Administration lifted price controls.

Table (1): Overview of Oil supply disruptions and price hikes[13]
Source: Elaborated from data quoted by Hamilton (2003)

[13] Data for the empty cells could not be found or were inappropriate.

Figure 12 underneath depicts the quantity dimension of past oil shocks from 1972-2011 in the case of OPEC and NON-OPEC countries. It clearly documents how increases of production of Non-OPEC countries, foremost from the North Sea, partially compensated the reduced oil output of the OPEC members during the two oil shocks.



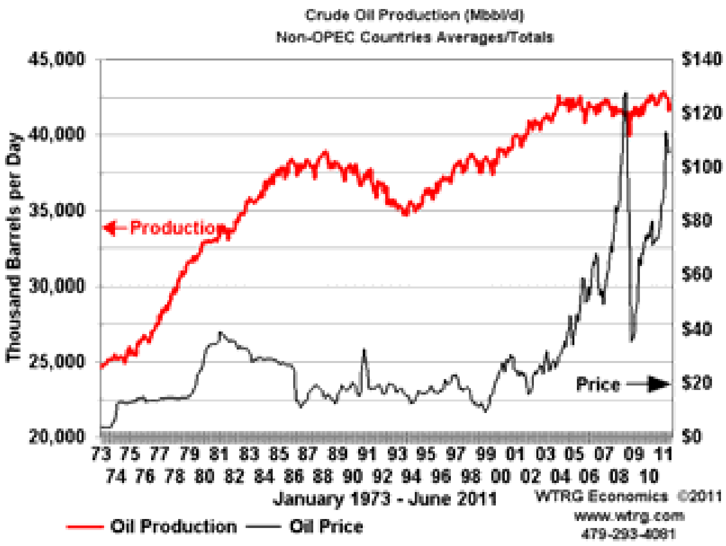
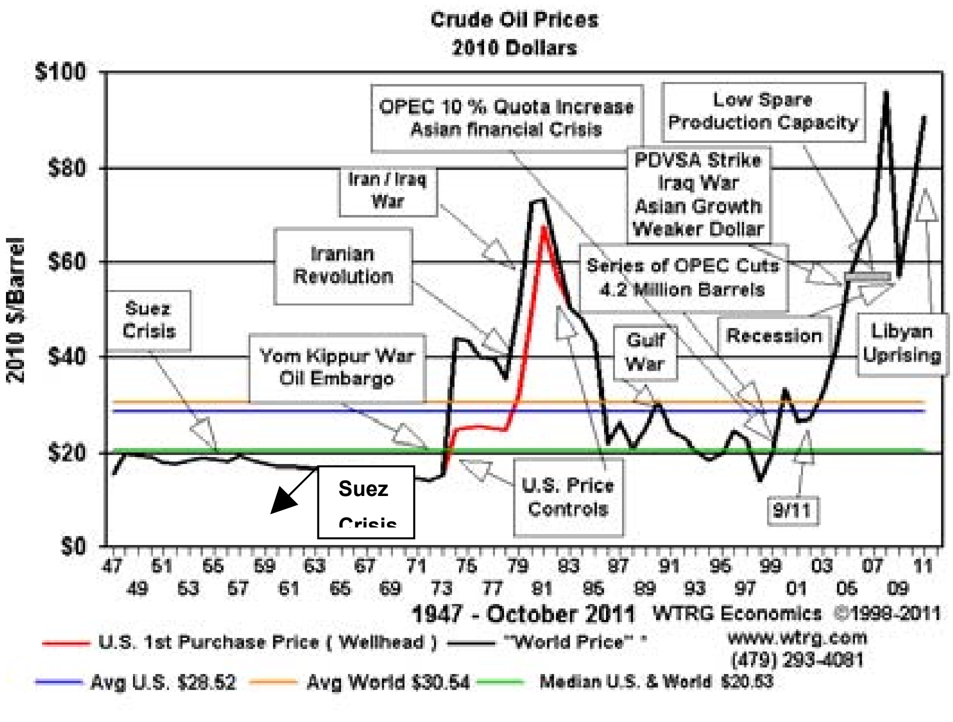


Figure 12: OPEC and NON-OPEC Oil production and oil prices 1973-2011
Source: Oil price History and Analysis (Williams 2011)

Figure 13 on the other hand shows the price dimension of the oil markets from 1947 – 2011 and indicates the respective events, responsible for price hikes. Since about 2004 the world has been witnessing a series of abrupt oil price increases, breaking record levels over and over, without prices ever fully recovering. Minor supply disruptions as the one caused by Hurricane Katrina in summer 2005, had already large effects on international stock markets and oil prices. However no geopolitical or other external event matches the dramatic oil price scenario during the crises of the late 70ies and early 80ies. Figure 13 emphasises the enormous impact caused by less than 10% decrease in WOP during these shocks. This event is only superseded in history, when without any obvious outside intervention (apart from speculation maybe), oil prices rose dramatically until reaching an unprecedented global record level of 145.16 US$/barrel (Cushing, OK WTI Spot Price FOB) on the 14th of July 2008 (EIA 2012). The reasons for this price escalation, and its possible link to the financial crisis of 2008-2009, are still subject to speculation (Hamilton 2009; Kaufmann, Gonzalez et al. 2010), but many "peakoilists" argue that this price spike has already been due to limited supply capacities (Murphy and Balogh 2009; Theramus 2009; Lewis 2010; Chanel 2012).



*"World Price - The only very long term price series that exists is the U.S. average wellhead or first purchase price of crude. When discussing long-term price behaviour this presents a problem since the U.S. imposed price controls on domestic production from late 1973 to January 1981. In order to present a consistent series and also reflect the difference between international prices and U.S. prices we created a world oil price series that was consistent with the U.S. wellhead price adjusting the wellhead price by adding the difference between the refiners acquisition price of imported crude and the refiners average acquisition price of domestic crude."(Williams 2003)

Figure 13: Real crude oil prices and disruptive events 1947 -2011
Source: Oil price History and Analysis (Williams 2011)

The era just before, during and immediately after the oil shocks in the 1970ie and 80ies was characterised by an increasing awareness of the finiteness of the world's natural resources and concerns about the wellbeing of the environment. This was expressed in a large variety of scientific (and non-scientific) publications (e.g.: Ehrlich and Holdren 1971; Georgescu-Roegen 1971; Meadows, Meadows et al. 1972; Georgescu-Roegen 1976; Meadows 1977; El Serafy 1988; Daly and Cobb 1989).

During this period there was also an increased interest in studying the effects of supply constraints on the macroeconomy, for example with IO Analysis (e.g.: Augustinovics 1970; Ehret 1970; Kutscher and Bowman 1974; Penn, Irwin et al. 1975; Beyers 1976; Giarratani 1976; Penn, McCarl et al. 1976; Giarratani 1981; Cartwright, Beemiller et al. 1982; Leontief 1983; Davis and Salkin 1984; Bon 1986; Chen 1986; Chen and Rose 1986; Allison 1989). However these concerns started to fade again in the early 1990ies as oil prices remained at more or less double of what they had been before. Despite more frequent variations prices fluctuated within a narrow range from the mid 1980ies to about 2002/03. Since then prices are on the rise again and so are concerns about future energy security throughout the world (Birol 2008; Greer 2009; Radetzki 2010).

2.3 Links to other Resource Peaks

2.3.1 Coal as a substitute for oil - the myth[14, 15]

Given the uncertain future of supplies of crude oil and its derivatives, many uncertainties surface about fossil fuels in general, especially coal. Adding to the traditional myth of oil having replaced coal, a new myth has begun to circulate that this trend may now be reversed given the relative abundance of coal reserves.

First, it's important to note that the use of coal has never decreased at any point in history. On the contrary, as illustrated in Figure 16, it has constantly been on the rise. In fact, it is the fuel whose use has increased most in the last few years (between 2000 and 2005, coal use rose by an annual average of 4.8%), especially due to the increase of demand by India, Japan, South Korea, and above all, China. The majority of global consumption is comprised of high quality coal (i.e. bituminous coal or anthracite) 5000 Mt/yr in 2005. Practically all of the total increase in the last few years has been comprised of high-quality coal, while the demand for low-quality coal (i.e. peat or lignite) has remained stagnant at some 1000Mt/yr. This

[14] This article is an updated translation of Part II (p. 30 -35) of Kerschner, Bermejo et al. (2010).
[15] Translation from Spanish to English: Brian Russell and Christian Kerschner.

significant increase in consumption has not been compensated for by the discovery of major new reserves, and as a result, the remaining reserves are being tapped into at an ever-increasing rate, particularly those of high-quality coal.

In general, one can say that coal hasn't been a replaced by oil, but that its main functions and applications have changed. For example coal is almost never used for transport anymore, while its use as a fuel for electric power production and the fabrication of products which require great amounts of heat, such as steel and cement has greatly increased. 58% of the total consumption of coal winds up producing electricity and the remainder is used in three major ways: housing, cement production, and steel production. This means that in countries with large reserves of coal, the majority of the electricity is produced by burning coal: China (79%), Australia (77%), India (68%), the USA (51%), South Africa (92.4%) and Poland (94.7%). Russia is an exception (17%), owing to its abundance of natural gas and oil.

The long-term future of coal depends in large part on China. This Asian country is by far the largest consumer (it uses 40% of global coal, which represents 69.5% of its primary energy consumption) (Zhou 2010), though it is estimated that it has only half of the reserves of the U.S., which means13.9% of proven global reserves (BP 2009). Between 2002 and 2007, China constructed around 500 coal-burning power plants and India roughly 200. In that same time, the USA has reduced its projected growth: of 151 programmed plants, 59 were cancelled. Growth of European consumption is stagnant, though the exhaustion of its reserves has caused an increase in imports. China, which has imported massive quantities of coal since 2007, monopolised Australian and South African exports. This caused a major rise in coal prices: in 2007 coal for steel production went from $115 to $210 per tonne and the price of coal for electricity production doubled, reaching $150/tonne (Kavalov and Peteves 2007; Hughes 2008; Oster and Davis 2008).

2.3.1.1 Coal transformation, CO_2 emissions and Carbon capture and storage

The physical and chemical nature of coal represents a main limiting factor when considered as a candidate for replacing oil. Coal is a solid fuel with a lower energy content than oil. Oil has been assigned a set of uses and functions specific to its quality and flow-quantity. For coal to replace some of oil's main applications - oil covers between 80% and 95% of the necessary energy in the transport sector, and 99% of lubricants (Skrebowski 2008), it must be converted to a fluid through one of the three known liquefaction processes (Karrick, Bergius, or Fischer-

Tropsch). In this way, coal can be transformed into synthetic fuels (synfuels), such as diesel. It is a technology that was developed in countries which have passed a period of political isolation. During the Second World War, Germany produced as much as 9% of its liquid fuel by converting its abundant coal reserves through the Fischer-Tropsch process. Currently, the main producer of these types of coal is Sasol, a South African company which owns the only commercial CTL (coal to liquid) plant in the world[16]. However, the total production of CTL, around 240,000 bbl/day (Wikipedia 2010b) is still insignificant to be considered as an alternative to oil with the immediacy of peak oil

Of course, it is possible that the scarcity of oil could cause the construction of liquefaction facilities in countries with large coal reserves. However, this alleged alternative to oil offers neither the quality nor quantity necessary to take on an important role in the future of global energy. The 2nd law of thermodynamics states that any process of energy transformation results in an irrecoverable loss of energy. The final amount of useful energy in respect to the primary energy of a particular source is its thermal efficiency. By this indicator, the Fischer Tropsch process implies a loss of between 45 and 55% (Liu 2005), compared with 5-10% loss in the process of refining petroleum. In other words, to obtain the caloric equivalent of one litre of gasoline, one would need to use nearly twice as much in terms of energy of coal than if produced from crude oil. All of this supposes a significant increase in the generation of CO_2 emissions compared to those generated by the use of petroleum derivatives which could be as high as 147% (Tarka, Wimer et al. 2009). For this reason, the proposals for new CTL projects are gambling on the application of possible technologies of carbon capture and storage (CCS), and there is even speculation about the possibility to reduce total carbon emissions during its life cycle with that technology (Tarka, Wimer et al. 2009). There is also talk of the development of new processes of CTL, such as direct liquification (DCL) but just as with CCS, this is in test trials and there is no experience in large commercial plants.

The concrete application of CCS could be seen as another myth of coal's future promise. The supporters of CCS tend to omit that, just as CTL, energetically it is a very costly process, which implies a loss of energy between 14 and 40% (Koppelaar 2010). Figure 14 shows the

[16] There are two factors which led South Africa to gamble on this technology: its enormous coal reserves (8th in the world, with 3.7% of the Global URR according to BP 2009) and the need to guarantee the supply of liquid fuel during the international embargo against Apartheid.

additional energy necessary to introduce a CCS processes[17]. It is important to point out also that for geological storage of CO_2 to become commercially viable major technical obstacles have to be overcome still (e.g. Kharaka, Cole et al. 2006). Finally, and most importantly the possibility of unpredictable and uncontrollable CO_2 leaks could be a serious risk for future generations. Another thing that CTL and CCS have in common is that they require large investment in plants. We are not aware of any studies which have calculated the EROI of CCS or of the combination of CTL-CSS, but the EROI of CTL is around 0.5 and 8.2, meaning it could even be less than one (Cleveland, Costanza et al. 1984). By comparison, direct use of coal is believed to have an EROI of around 80 (Murphy and Hall 2010).

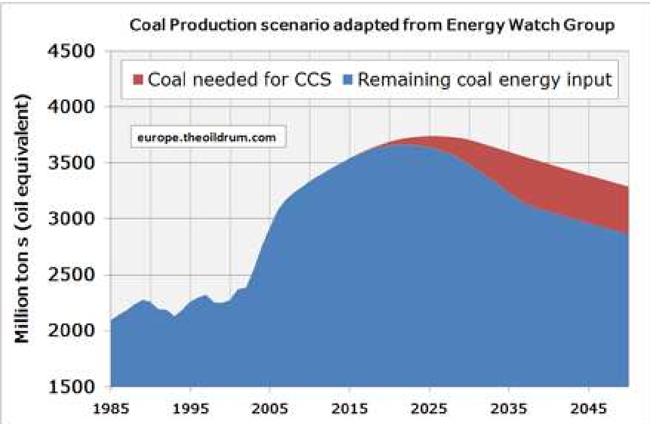


Figure 14: Scenarios of coal production calculating the energetic costs of CCS
Source: Koppelaar 2010

2.3.1.2 Peak Coal: limits of reserves and flow

As stated previously, another of the major barriers to be overcome if coal is to replace oil will be the matter of quantity, starting with reserves. Here we find another one of the myths surrounding coal, that of its abundance(Bermejo 2008). Recent studies show us that there is a lot less coal than what is generally assumed,[18] and aside from that, it is getting used up at a quicker rate than that of other fossil fuels. Coal reserves are divided into two groups, those of high and low energy content. The contained energy varies from 14 to 32.5 Megajoules/kg.

[17] Owing to these enormous costs, should this technology be adopted, there will be incentives to "disactivate" the CSS process, or reduce its use, above all in times of crisis. As a case in point, it is not known whether China is currently using sulfer-cleaning systems in its coal-fired power plants due to the economic and energetic costs that such devices entail. (Zhou 2010)

[18] Evidence for this hypothesis is advanced by the dramatic increase of accidents in subterranean coal mines, since mining companies are entering increasingly into unstable underground strata. Recent examples include the accident in Virginia, Australia in 2010, or the Crandall Canyon mine in the USA in 2007. China is an extreme case. Only in 2005, 6000 coal miners died the majority in small mines, which despite their size, taken together contributed a third of the coal production in the country. China's State Council wants to close more than 10,000 of these dangerous mines, but it would mean a reduction in production of more than 250 million cubic meters. ibid.

Low-grade types of coal are slightly more abundant as high-grade types of coal – 53% and 47% of global reserves respectively. , Coal is concentrated in specific geographic areas; six countries (the USA, Russia, India, China, Australia, and South Africa) are believed to possess 85% of global reserves of high-grade coal. The first three and Australia also own the majority of low-grade coal. The US has 30% of global reserves (it comes second in terms of extraction and is responsible for 9% of total global consumption), followed by Russia and the rest of the countries mentioned above. Australia, Indonesia, South Africa, and Colombia are the principal exporters, in that order. But the total volume of international trade is a small fraction of that of internal consumption. Coal exports from Australia to China for example only represent 5% of Chinese consumption for electricity generation. It's likely that Australia will remain as the world's only exporter of coal soon (Kavalov and Peteves 2007).

One cannot know with certainty the global URR for coal, because few countries evaluate their reserves periodically, and as such the data is more imprecise than in the case of oil. However, since 1986, all countries which did evaluate their coal reserves have made significant downward corrections, except for Australia and India. The magnitude of corrections of the following countries stands out: Germany and the UK with reductions of more than 90%, Botswana with (90%) and Poland with (50%). For this reason, many reports agree that coal is indeed scarce, even though the estimates of reserves vary significantly. One EU report arrived at the conclusion that "in the future, coal may not be as abundant, widely found, or reliable as a source of energy" (Kavalov and Peteves 2007, p.36). In the same year, the US National Academy of Sciences (after verifying that previous estimations were acquired using obsolete methods) confirmed that "only a fraction of the previously estimated reserves can now be considered for exploitation" (National Academies 2007).

Just as is the case of oil, coal has a maximum peak of extraction, as illustrated in the following figure, which shows (yet again) that the size of the URR as a stock variable may be misleading, when looking at global flows. In reality, there are two peaks in the case of coal, one of volume and the other of energy, owing to the great inequalities of the different classes of coal. Since high-grade coal is generally consumed first (best first principle), the energetic peak occurs before the peak in volume. Global extraction of coal in energy terms (i.e. millions of tonnes of petroleum equivalent) is set to grow 30% until reaching its peak in 15 to 20 years (around 2025) (Zittel and Schindler 2007a). M. Möök predicts a global energy peak in 2020 followed by a plateau for 30 years (Kerr 2009). D. Hughes (2008) estimates that the Peak-

Coal will occur in 2030. Rudledge doesn't define a limit, but estimates that by 2069 we will have consumed 90% of global reserves (Kerr 2009). Once the peak is reached, extraction will gradually drop until 2050, and rapidly thereafter. But long before the peak, between 2010 and 2015, the rate of extraction will have fallen enough to be unable to satisfy the demand, as is shown in Figure 15. The USA will reach its energetic peak in 10-15 years and it cannot be expected that the current rate of extraction will rise considerably. China is also approaching its energetic peak (Zittel and Schindler 2007b).

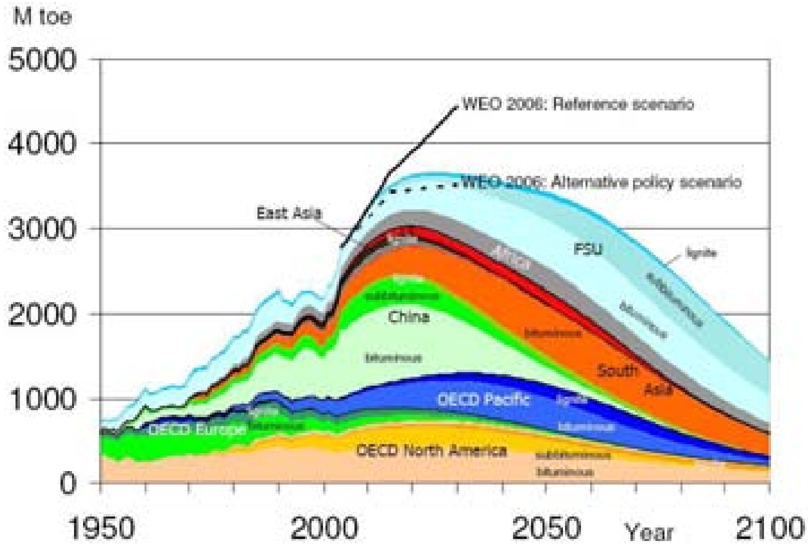


Figure 15: Peak coal by energy (WEO refers to World Energy Outlook, the annual report of the International Energy Agency)
Source: Zittel and Schindler, 2007b, p.19

2.3.1.3 Possible effects of Peak-Coal and the peak of all fossil fuels

Difficult as it is to make predictions about the potential effects of Peak-Oil, with Peak-Coal, it's almost impossible to know, since the economic system has been accustomed to its growing availability and quality for even longer. Moreover the peaks of different resources will not be independent from each other. Hence the scarcity of oil will have major impacts on daily extraction rates (flow quantity) of coal, because during the entire production chain from mining until transport to consumers requires large quantities of oil. In China, for example, the majority of coal is transported by lorry (Zhou 2010). See also Friedrichs (2010) account of how the 1990ies North Corean oil crunch paralyzed the countries coal industry and therefore the entire country – 600.000 to 1million North Koreans died in the resulting famine. It's very improbable that a fossil fuel such as coal could easily compensate the peak of another such as oil. It's more likely that an interconnected fossil fuel peak will produce, as shown in Figure

16, causing a generalized energy crisis. Such a graph is of course mostly for illustrative purposes, as it would be an impossible task to reliably predict such a peak.

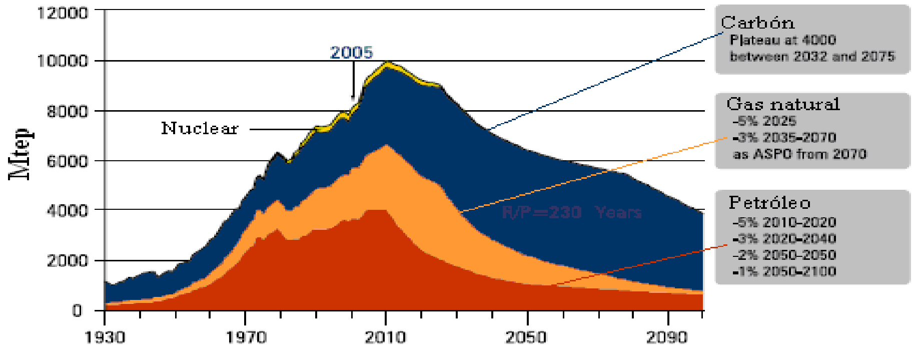


Figure 16: A tentative illustration of the peak of all fossil fuels and nuclear energy.
Source: Zittel et al., 2007

2.3.1.4 Concluding: Peaks and climate change

Although what has been put forward up till now can be seen as a bleak outlook, not all of the effects of the mentioned peaks are negative. In fact, for the rest of the living species who share this planet with us, and for the environment in general, the scarcity of fossil fuels could be very good news indeed. Apart from other contaminants which are released by burning energy resources, and the huge amount of damage that our energy affluence causes to ecosystems, the peak of fossil fuels implies a progressive reduction in CO_2 emissions, a major contributor to the greenhouse effect. However, oddly enough, this opportunity has been overlooked by the ***Intergovernmental Panel on Climate Change*** (***IPCC***) while working out scenarios which are the point of reference for policy regarding climate change.

In IPCC scenarios, the demand for fossil fuels, and consequently, CO_2 emissions are conditioned by the evolution of economic, demographic, and technological factors, but not geological ones. The existence of a peak in extraction rates for different fuels enters into direct contradictions with this approach: it is the availability of fossil fuels that will result in economic growth and CO2 emissions, and not the other way around. As well, over the length of the decade, experts in fossil fuels (e.g. Aleklett 2007) have expressed their surprise because the consumption scenarios of the IPPC were based on fossil fuel reserves far greater than those they estimated, to the point that 17 of the 40 IPCC scenarios of fossil fuel consumption in 2100 are higher than current consumption. The German Mineral Resources Agency estimates the combined global reserves of fossil fuels to be 2.7 billion barrels of petroleum equivalent (Bbpe) (Rempel, Schmidt et al. 2009). BP's figures reach 3.2 Bbpe. The CME estimates them at 3.5 Bbpe (Rempel, Schmidt et al. 2009). On the contrary, the IPPC bases its estimates on the premise that there are 11-15 Bbpe (e.g. IPCC 2000; IPCC 2002).

Both circumstances shed doubt on the scenarios of the PICC, firstly that it is apparently systematically overestimating CO2 emissions (Brecha 2008; Höök, Sivertsson et al. 2010; Patzek and Croft 2010), and secondly because of its hypothesis of unlimited economic growth upon which these scenarios are constructed. This is not to dismiss the seriousness of climate change of course, which is already taking place and is certain to worsen as time passes, but to underline the problem of distribution of ever scarcer amounts of energy resources.

As well, many of the solutions to both problems converge, because the problem of an energy scarcity should not be seen as a threat in the fight against climate change. The necessary adaptive policy action to both issues is essentially the same: trying to reduce already now the flow rate of fossil fuels. This will on the one hand reduce CO2 emissions per year, slowing down the problem of climate change and on the other hand allow a smoother transition to a low carbon and steady state economy (see Part 4). In this way future generations would be guaranteed the possibility to enjoy a stable climate and have access to certain non-renewable resources of great value. The Yasuní-ITT proposal of leaving oil underground (Rival 2010)[19] and the Rimini Protocol to adapt consumption to the proportion of discoveries (Campbell 2006) are good policies towards that end.

2.3.1.5 Acknowledgements

Christian Kerschner wishes to appreciate the support he has received from the **ECO2009-10003 project**, "*Public Policy and Economic Analysis*" which was financed by the Spanish Ministry of Science and Research and Development and Innovation.

2.3.1.6 References

Please note references of this article have been integrated in the bibliography of Part 2.

2.3.2 Peak phosphorous

The same logic applies to phosphorus (P) and many other non-renewable resources. P is a critical resource to industrial societies in the form of fertilizers and its depletion is also

[19] www.yasuni-itt.gob.ec

expected within this century. There is no substitute for phosphorus in food production and without sufficient access to phosphorus fertilizers, food cannot be produced at yields that can feed the growing world population. Interestingly, given its importance (see Box 1), neither its depletion nor its peak seem to create a lot of attention at the national or international policy levels (see Box 1). According to Cordell et al., the decisive moment of peak P is expected to occur between 2040 and 2050 (Cordell, Drangert et al. 2009).

Experts suggest that we could deplete our global reserves of this non-renewable resource in this century, while the peak phenomenon suggests reserves could peak in the next few decades.

Peak phosphorus is both similar to and affected by Peak-Oil. The peak of production of P is estimated to occur within decades of the oil peak. According to some industry scenarios (Steen 1998; European Fertilizer Manufacturers Association 2000), peak P will occur around 2040, illustrated in an indicative 'Hubbert peak' in Figure 17. While the exact peak will depend on numerous factors like demand and price of oil, the fertilizer industry does not deny that the grade and quality of the mineral resource is decreasing and the cost of extraction and refinement is increasing (International Fertilizer Industry Association 2006). Cadmium and other associated heavy metals can be present in high concentrations in phosphate rock, which are either too toxic for receiving soils or costly and energy-intensive to clean (Driver 1998; Steen 1998). However technological optimists object that new technologies will improve efficiency of extraction in the future (Stewart, Hammond et al. 2005), so there is no need for concern.

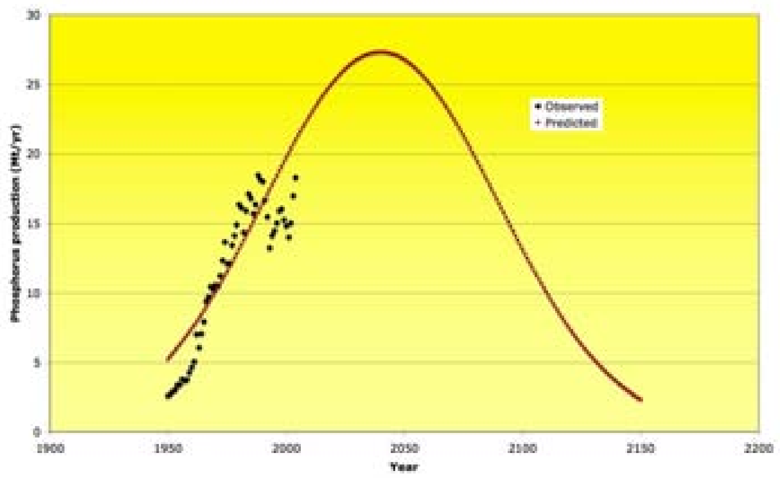


Figure 17: Indicative peak P curve, illustrating that, in a similar way to oil, global phosphorus reserves are also likely to peak, after which production will be significantly reduced. This assumes that the reserve totals approximately 3,400 Mt, based on estimates from (Gunther

1997), plus cumulative production up to the mid-1990's, and that the peak production will be in approximately 2040 (European Fertilizer Manufacturers Association 2000). Graph from (Cordell, Drangert et al. 2009).

There is one important way in which P differs from oil. Oil can be substituted with other forms of energy, particularly renewable sources (Cordell, Drangert et al. 2009). However, there is currently no known substitute for P in food production (Jasinski 2006). Other differences are highlighted in Table (2).

Attribute	Oil	Phosphorus
Peak discovery	Peak discovery occurred in the 1960s (Aleklett 2006).	unknown due to lack of available and accessible data.
Peak production (= peak resource)	Expected to occur between now and 2030 (Sorrell and Speirs 2009)	estimated at around 2040
Depletion	At current consumption in about 40 years (BP 2009).	At current consumption in 50-100 years (Steen 1998; Stewart, Hammond et al. 2005).
Dependency	Modern societies dependent / addicted to cheap oil. Products made of hydrocarbons are all around us and are crucial for energy and food production, transport, etc.	Similarly for P. Geochemical realities – phosphorus is essential for food production yet it is predicted that demand for P will exceed supply of known P reserves in the near future (Rosmarin 2004; Cordell, Drangert et al. submitted).
Substitutability	Substitutable, but not in the quantities and qualities needed	Non-substitutable. P (along with N and C) is a critical nutrient for food production (Mårald 1998; Gunther 2003?).
Future demand	Future demand for oil is increasing both in per-capita and absolute terms. This is largely due to its link to economic growth.	Future demand for P is predicted to increase by 2.3%, largely due to increased food demand in the developing world. A meat-based diet also consumes significantly more P than a vegetarian diet (Fresco 2003; Jasinski 2006).
Geographical distribution	Highly skewed global reserves – creates geopolitical tensions (e.g., dependence on Middle East, since US hit peak oil in 1971). The UK´s oil production from the North Sea peaked in 1999. Australia peaked in 2000 (Leggett on ABC, 2005).	Geographically highly distributed (reserves are mainly in Western Sahara (controlled by Morocco), China, US; US reserves to be depleted in 25 years (Rosmarin 2004; Jasinski 2006).
Geopolitics	High geopolitical tensions as a result of scarcity and natural distribution; e.g., Middle East and US. e.g.: Stern (2007),Stern (2006), Klare (2004); Deloitte (2009), William (2005), Clonan (2008)	Similarly, P is likely to experience increased geopolitical tensions due to geographical distribution. Already tensions exist in Western Sahara, Morocco, US (Rosmarin 2004).
Food Production	Oil and petroleum products are essential for fertilizer and food production (Pfeiffer 2006).	90% of global P extraction is for crop production (Jasinski 2006).
Conversion efficiency	Depending on use but in the transport sector, which is the most important	A balanced diet results in depletion of around 22.5 kg/yr** of phosphate rock (or

	consumer, it is generally very low: around 30% otto motor, and around 40% diesel engine.	3.2 kg/yr of P) per person based on current practice. This is 50 times greater than the 1.2 g/d per person recommended daily intake of P (Cordell, Drangert et al. submitted).
Excess consumption (i.e., downstream impacts)	Oil and its derivatives are foreign substances to the natural environment. Hence once extracted it will evidently cause pollution of some sort. Burning oil as fuel is among the largest contributors of CO_2 emissions and hence to climate change.	Excess P consumption can result in discharges of toxic levels of P, potentially eutrophying receiving water bodies, threatening the environment and public health.
Tangibility	Almost all actors, including citizens, understand the significance of oil (i.e., energy), partly because it is a tangible symbol in our society. For example, automobile users directly consume oil at the petrol station.	Very few actors (especially citizens) understand the significance of phosphorus, as it is far less tangible than oil or water. Although humanity also depends on phosphorus, it is consumed indirectly through food. Most people have never seen phosphate rock in the media, let alone in real life.
Arenas	The peak oil phenomenon is currently limited to discussion among concerned scientists and academics, but not in the public arena nor decision-making / negotiation arena over oil / energy.	Peak phosphorus is a phenomenon not yet accepted in ANY arena, including global food security, fertilizer, public arena generally, nor the appropriate decision-making arena for natural resource use.

Table (2): Comparative analysis of the attributes of peak oil and peak phosphorus

2.3.2.1 Phosphorus and food security[20]

Regions such as sub-Saharan Africa, already suffering from phosphorus-deficient soils and inadequate food supply, will face additional difficulties in achieving the target of the Millennium Development Goal on eradicating hunger. With such a contradictory and challenging situation, it is surprising that the role of future phosphorus scarcity is not well recognised in the food security debate. Options for increasing ‘phosphorus sovereignty’, including readily available and renewable phosphorus supplies from human and animal waste, will need to be explored further.

According to the FAO (Fresco 2003), global food production will need to increase by about 60% by 2030 to meet the global demand. With 2-2.5 billion new mouths to feed by 2050 (IWMI 2006) mainly in urban slums in the developing world, and more people eating more meat and dairy products (Steen 1998; Smil 2000; Stewart, Hammond et al. 2005), finding enough P to grow food is likely to be a significant challenge for humanity in the future.

[20] (excerpts from Greer 2008)

This increasing demand for non-renewable phosphate supplies should be a significant issue given that future food security is now considered a global priority (Runge-Metzger 1995; FAO 2000; UN 2000; IFPRI 2002; SIWI-IWMI 2004). However, there is little or no mention of future P scarcity as a key factor limiting future food security.

More recently it is acknowledged that energy and water will be critical issues for meeting the future nutritional demand of a growing population (Smil 2000; Pfeiffer 2006). Experts suggest that a radical shift in the way we think about and manage water is required in order to meet this demand (Falkenmark and Rockström 2002). However, just as food security faces 'hydroclimatic realities' (p.5, (SIWI-IWMI 2004)) of water availability, so too does it face the 'geochemical realities' of limited P reserves.

Similar to oil, the world's major reserves of P are geopolitically concentrated, situated predominantly in China and Western Sahara. High-concentrate phosphate rock is only present in a limited number of geographical locations partly because P has no atmospheric component and has taken millions of years to form in the lithosphere via uplifted deposits on the sea bed (Smil 2000). Morocco currently controls Western Sahara's reserves, which represent more than a third of the world's supply of high-quality phosphate rock. While US reserves are predicted to run out within 30 years, the US remains the greatest exporter of P-based fertilizer due in part to massive imports of phosphate rock from Western Sahara under Morocco's control (Stewart, Hammond et al. 2005; Jasinski 2006). Western Europe and India are totally dependent on phosphate imports. China, the other major location of reserves, appears unlikely to import or export its resources (Rosmarin 2004).

Given this situation, and the fact that there is no substitute for P, it is of concern that limited attention is being paid to this issue in the global discourses on food security. Shifting dependence from importing phosphate rock to domestic production of renewable P fertilizers (like humanure and biomass) can contribute to countries' P sovereignty.

Reliance on geographically concentrated phosphate rock to produce fertilizers means phosphate rock and fertilizer products must be transported across long distances around the globe, adding significantly to fossil fuel consumption and hence the embodied energy in food products.

2.4 Governing global resource peaks

2.4.1 Institutional Response to Peak-Oil and other Resource Peaks so far

The common mantra of mainstream economists is that market forces, driving up oil prices when scarcity increases, will inspire human ingenuity to develop substitutes and alternatives for oil or other non-renewable resources (e.g. Barnett and Morse 1963; Solow 1974; Lenssen and Flavin 1996; Adelman and Lynch 1997; Lynch 1999; Odell 1999; Hisschemoller, Bode et al. 2006; Jackson 2006; Maack and Skulason 2006). In line with this reasoning Saudi Oil Minister Sheikh Ahmed Zaki Yamani famously said: "The Stone Age came to an end not for a lack of stones and the oil age will end, but not for a lack of oil" (Mably 2000 p. 1).

Probably due to this dominant paradigm, official institutional responses to the problem of Peak-Oil and resource peaks in general are still very rare (Cordell and Kerschner 2007). The most influential statistical organisations for energy questions i.e. the International Energy Agency (IEA), the energy watchdog of the OECD; the US Energy Information Agency (EIA) of the US Department of Energy (DOE) and the (much less important) European Energy Portal, still refrain from using the “P-word”. Instead, as already mentioned they focus on the stock dimension of quantity and continue to communicate reserve-production ratios, which give the illusion that issues of energy scarcity are still quite far away. One can only speculate about the reasons for this attitude, but they are most likely political rather than data related. However voices calling for attention to the matter have been increasing over the last years.

It started with the so called “Hirsch-Report” (Hirsch 2005), which was commissioned - but never acknowledged (EB-staff 2004) - by the U.S. DOE. It concluded that Peak-Oil will cause an energy crises never seen before and will result in “…protracted economic hardship..” (p.5) caused by dramatically higher oil prices. “Mitigation…”, so it continues, “…will require a minimum of a decade of intense, expensive effort…” (p.5). Officials within the IEA are also growing increasingly nervous about an imminent energy crises (e.g. Birol 2008), and according to a whistleblower the agency is under pressure from the US administration to varnish its numbers (Levitt 2010). Business in the UK also feel a lack of attention to Peak Oil and a group of major companies (including Virgin), have created the Industry Taskforce on Peak Oil and Energy Security (ITPOES)[21], which is lobbying the UK government to address the issue. Last but not least the US Pentagon, the largest single consumer of oil products in

[21] http://peakoiltaskforce.net/

the world, warns in a Report released in spring 2010 that: "By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 million barrels per day"(USJFC 2010, p 29).

2.4.2 Institutional analysis of peak oil and peak phosphorus phenomena

Nevertheless to date there has not been any official document, by a government agency or other organization like the IEA or EIA, which describes Peak Phenomena (Oil, Coal, Phosphorus, etc.), warns of its dangers and calls for policy action. Why are Peak Phenomena not addressed in the appropriate arenas? In a paper with my colleague Dana Cordell (Cordell and Kerschner 2007), we argued that the institutional arrangements surrounding global non-renewable key resources and the dominant paradigms and norms that inform them are one of the reasons for the lack of attention and subsequent institutional change. For this purpose we conducted the following institutional analysis.

2.5 Application of adapted Vatn framework[22]

This Chapter presents the institutional analysis of key global non-renewable resources, using peak oil and peak phosphorus as cases. The framework (see Figure 18) has been modified from Vatn (2005) to better suit the governance of global non-renewable resources at the international level.

[22] This Chapter reproduces the adapted and shortened part 4 of Cordell and Kerschner (2007).

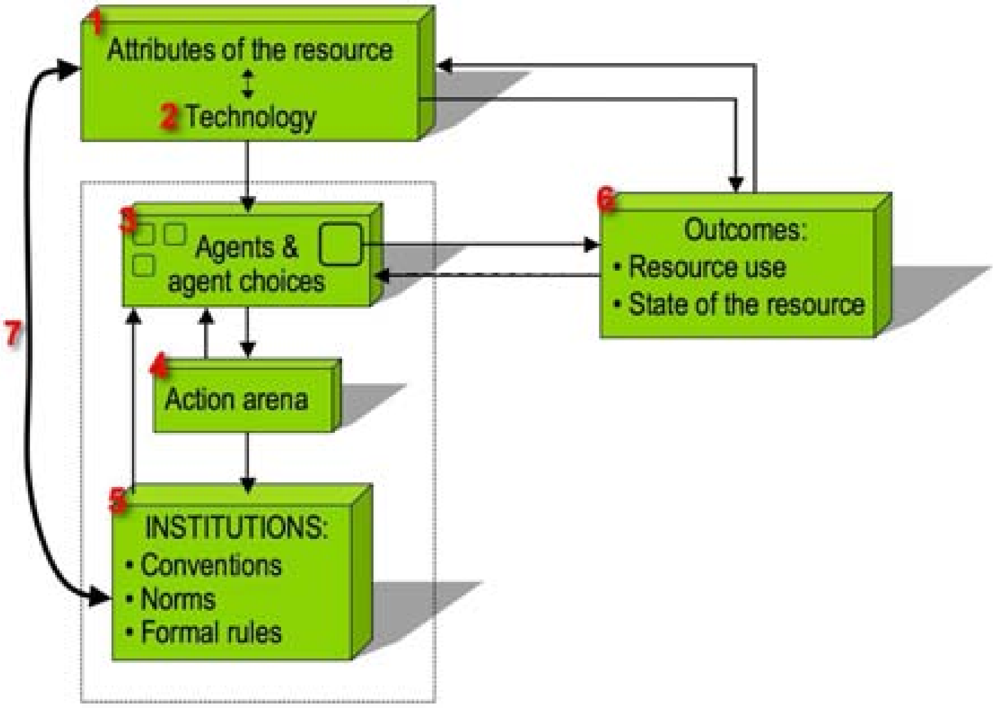


Figure 18: The modified Vatn (2005) framework for institutional analysis of GNoRK resources.

The key modifications include shifting 'patterns of interaction' from the physical realm between agent choices and outcomes to the patterns of interaction in the social space occurring between 'agents' and 'institutions'. This has been renamed 'action arena' after Ostrom (2006). The action arena is the space where issues are discussed, negotiated, goods are exchanged and decisions made. Outcomes from the action arena are highly influenced by powerful agents. Therefore, a final modification is to make explicit those agents with a high degree of power. This is elaborated in Section 4.2.3 below. As noted by Young (2007), a key feature that distinguishes the problem at the local versus global scale is that the appropriators and managers tend to be the same actors at the local scale, but not at the global scale. In the case of oil and phosphorus, the appropriators are firms and nation states, whereas the managers are international organisations.

For the purpose of this analysis, we define institutions after Vatn (2005):

> *"Institutions are the conventions, norms and formally sanctioned rules of a society. They provide expectations, stability and meaning essential to human existence and coordination.*

Institutions regularise life, support values and produce and protect interests" (Vatn 2005, p. 60).

Such a social constructivist perspective "*focuses on the dialectics between agents and structures. Individuals form institutions... [and institutions] form individuals*" (Vatn 2005, p. 54). It is indeed our intention to explore the tension between these two 'irreducible entities' (p. 57) and thus the focus of this analysis lies in the space within the dotted lines (Figure 18). We view institutions as both playing a role in causing problems of ineffective governance of global non-renewable resources, and a space for solutions, or redesigning of institutions (Young 2005).

2.5.1 Attributes of the resource

In this paper we focus on a family of resources which we define as **G**lobal **N**on-**R**enewable **K**ey **R**esources (**GNoRK Resources).** Given the fact that strictly speaking there are no non-renewable resources, we are using the term to define resources which are not renewed within a human time scale (i.e., a few generations) but only in geological time (thousands of years or more). Thus, it is for example currently not possible to recollect the emissions from burning petrol and reconvert them into fuel. The same is true for nonpoint source phosphorus fertilizer runoff that ends up in rivers and eventually in the sea (Cordell 2006).

Moreover, we specify that the resources we are interested in are those that have a geopolitical aspect. This means that they are a key input in almost every economy, while their deposits are concentrated in a few regions around the globe. We decided for this definition because we believe that these resources have common properties with regards to their institutional management. GNoRK resources, such as oil and phosphorus, are 'lynchpins of human society' (Rosmarin 2004).

2.5.2 Technology

The technology which is available for the exploration, extraction and refining (EER) of a resource, or the opportunities given by it (Vatn 2005) are highly influential with regards to non-renewable resources. Renewable resources, if not depleted to extinction, are unlimited in terms of the total amount eventually harvested (within the lifetime of the Sun). Hence there will be a certain limit as to how technology influences extraction once it has reached the maximum sustainable level. Then institutional influences (regulations, quotas, etc.) will be much more important. An example would be the hunting of whales. Whaling fleets are already operating on such a high technological level that if left alone, they could very well drive whales to extinction in very little time. Hence the added value of more sophisticated whaling technology is minimal. In this case it is regulation and a theoretical ban on hunting of whales which dominate this resource.

In terms of non-renewable resources, on the other, hand it will be almost exclusively a matter of demand (market prices) and technology that will influence the extraction rate, as there is currently no institution that would regulate their extraction (the Kyoto protocol being a not very successful exception). Prices will to a large extent be determined by EER costs. Hence every time these costs can be reduced by new technology, extraction will increase. This is especially the case for resources that show a strong linkage to economic growth and the markets for which are not easily saturated, such as would be the case for many GNoRK resources.[23]

Oil may be an exception to this rule, as far as past strategic tactics of the members of the OPEC (Organization of the Petroleum Exporting Countries) are concerned. However, these days competition it faces by non-members, chiefly Norway with its North Sea oil, and international pressure (military and political) give the organisation fairly little room for independent actions. This situation may change again once the easily accessible sweet crude oil is used up or once North Sea oil peaks. No similar powerful agent exists in the case of the fertilizer industry. Hence their markets will be strongly dependent on EER technology and hence costs and more and more fertilizers would be consumed as prices dropped. Eventually there may have to be an institutional intervention in terms of limits to fertilizer use to reduce the detrimental effects of runoffs. Nevertheless, there are other limits. Similar to any non-renewable resource, the easiest accessible and purest stocks of phosphorus will and have already been exploited first (International Fertilizer Industry Association 2006), and the EER costs are already increasing (for example due to increased cadmium contamination and lower-grade phosphate rock (Driver 1998; Steen 1998), only to be potentially reduced by new technology. The costs of these technologies, however, will most likely also increase, e.g. returning to the case of petroleum, deep sea drilling is nowadays possible, but the technology involved is very complex and costly.

[23] Daly (1992), for example, argues that taxes imposed on such resources are often not effective, as the price increases caused by them may be partly circumvented by a push to new and cheaper extraction technologies often involving an up-scaling of the operations (bigger diggers, etc.).

Finally, it should be mentioned that, in terms of resource peaks, there is also a danger in technological improvements in EER which allow speeding up depletion and the commercialisation of lower grades of the resource. These improvements can either prolong the occurrence of the peak or transform it into a plateau for some time. The socio-economic danger in this is that the drop may be even faster once the peak of this technologically inflated reserve or the end of the plateau is reached. This would give society even less time for adaptation as the signals through price increases on world resource markets may not be strong enough to bring about the necessary policy initiatives for adaptation.

2.5.3 Agents and agent's choices

For the purpose of this analysis, agents are defined both as actors – that is, they have the capacity to act – and simultaneously as institutions – that is, they consist of conventions, rules and norms (Siebenhüner 2007). It is also consistent with the notion of holons, as each agent is a unique entity, yet also part of a greater system, and consists of a system within. Here, we have identified key agents as those international organisations who influence or are influenced by global non-renewable resource peaks. That is, those involved in the production, distribution, regulation, or monitoring of oil or phosphorus, or those concerned with the impacts of such resource use, such as adverse environmental and health impacts, and food production and food security in the case of phosphorus.

Although our analysis is specified at the international level, we also refer to nation states and firms that are key players in the action arena (e.g., negotiating the rules of resource governance) and therefore integral at the international level, such as key net resource exporters and importers.

It is clear that not all agents have the same influence over outcomes. Here, power imbalances are largely the result of the highly uneven geographical distribution of GNoRK resources, coupled with the dominant institutional structures (i.e., the market system) and a country's political power[24]. This power in turn influences the level of control or choice an agent has in relation to the outcomes (Ostrom 2007). Ostrom's notion for common-pool resource

[24] A country's political power is a direct reflection of its military power and GDP. For example, see the publicly available list of military budgets at http://www.nationmaster.com/graph/mil_exp_dol_fig-military-expenditures-dollar-figure.

situations that strangers in a 'state of nature' (that is, the default situation) tend to NOT obtain mutually beneficial outcomes, is true also for global non-renewable resources.

Motivations or 'interests' of the most powerful agents are key to outcomes of resource use and governance (Vatn 2005). For example, the net resource exporters (such as Saudi Arabia in the case of oil) have a disincentive to support any international policy initiative (such as the UNFCCC) to reduce global consumption of the resource. This seems counter-intuitive given the fact that the price of these resources has been increasing steadily in recent history. However, it is perfectly rational under the assumption of perfect substitutability and thus the option of importers not to buy any more once an alternative resource has been found. It is also rational given that most exporting countries have built economies that depend on the benefits from resource sales and need to maintain an inflated infrastructure (i.e., 'inertia'). See Figure 19 for a first attempt of a stakeholder analysis with regards to peak oil. More details for the underlying rationals can be found in Appendix I.

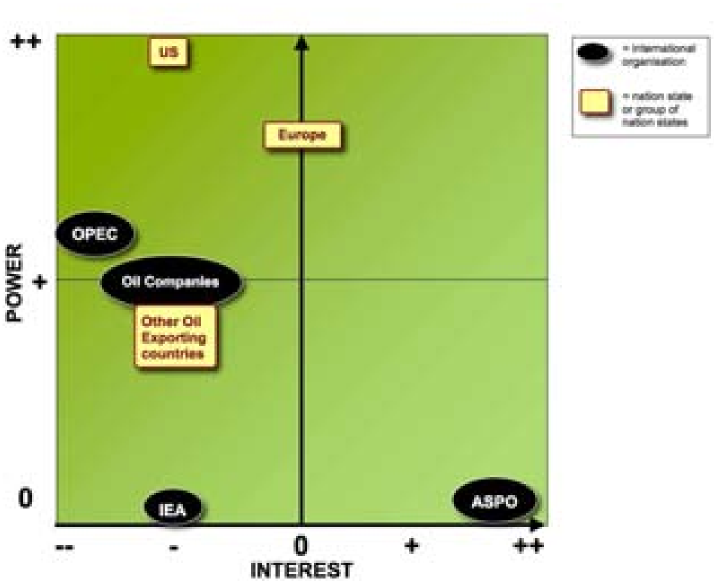


Figure 19: Illustrative representation of oil stakeholders' power versus interest in increasing awareness in peak oil and subsequent institutional change required for improved governance of global oil reserves.

Note: Greer (2008) have conducted a rigorous stakeholder analysis for the case of Peak Phosphorus.

2.5.4 Patterns of interaction - 'Action arenas'

We define the patterns of interaction in this social space between agents and institutions as the 'action arena'. According to Ostrom, an action arena is the '*the social space where individuals interact, exchange goods and services, solve problems, dominate one another, or fight*" (Ostrom 2006, p. 28). This differs slightly from our definition of 'appropriate arena', as the latter encompasses all arenas, whereas the action arena is the arena that results in action, therefore the decision-making arena.

Here, it is likely that the interests of the most powerful agents will prevail and influence the final outcome of the action arena, which in turn influences the GNoRK resource use and governance. In the case of phosphorus, this is likely to reflect the interest of the most powerful nations – the US and Morocco – and the dominant international industry bodies – the International Fertilizer Industry Association and the World Phosphate Institute. These players are to some extent representing a large infrastructure for fertilizer production and have a vested interest in maintaining the widespread use of phosphate rock fertilizers for food production.

Furthermore, these key powerful agents can control the market from the more centralised and international trade level. Therefore the politics of scale (Young 2007) plays an important role here, since the same agents could not maintain the same level of control over a more distributed market of phosphorus fertilizer production based on local scale through the reuse of renewable phosphorus in human excreta and food residues.

Also of interest is that peak phosphorus does not even have any voice in the action arena, unlike Peak Oil which, whilst not powerful, is represented by the Association for the Study of Peak Oil (ASPO). Peak P is not even on the radar and a point of discussion. Nevertheless, as the rudimentary stakeholder analysis of the issue of Peak-Oil above shows, no actor that has any power is interested in institutional change. This is probably the reason for the desperate formation of the ASPO. So in this case the pattern of interaction could be described as a "non-concerted conspiracy" of silence or as "acting as if it was not there".

Finally, it should be mentioned that national actors will also be lobbied in their decisions by powerful resource industry interest and will act according to the international relations theory of realism and the game theory notion of 'if you don't take it, I will' – Kyoto has shown very well that the international community is not willing to seriously start cutting down fossil fuel use. There is no wonder as they, and GNoRK resources in general, could be regarded as the "fuel for the race to power" (economic and military).

2.5.5 Institutions

In the following section we identify and analyse the dominant institutions involved in the institutional management of GNoRK resources, according to Vatn's distinction between conventions, norms and formal rules (Vatn's triad). In agreement with Ostrom (2006), we believe that only "once we understand the working rules, then we can attempt to understand where those rules come from" (p. 36) and to possibly change them in the future.

The most dominant institution according to our understanding is the *market*, which can be defined as "a place of exchange" and covers aspects in all the institutional spheres. This does not mean that there may not be other institutions involved in the issue: using the privilege of owning a GNoRK resource, and thus the option of "not selling for market prices" for political gains, may be an example (such is the apparent case with China choosing not to export any of its recently discovered phosphate rock reserves). However, we argue that they play a minor role at this moment in time. Furthermore, we argue that most other institutions that come to power within the management of GNoRK resources are embedded in or can be attributed to the overarching institution of the market. In accordance with the definitions provided by Vatn (2005) and Ostrom (2006), we argue that the market as an institution embodies all three elements of Vatn's institutional triad: conventions, norms, and formal rules.

2.5.6 Conventions

According to Vatn (2005), conventions "simplify by combining certain situations with a certain act or solution… a typical characteristic of a convention is that it solves a coordination problem' (p. 63). Modern markets would be impossible without such conventions. Language, physical measurements and money are all part of this category. The latter is particularly interesting, because it is the dominant denominator of "value" in our society. Similarly, borders and frontiers of individual states are used to determine, implement and police the formal rule of property rights to GNoRK resources.

2.5.7 Norms

Ostrom (2006) defines norms as: “the shared prescriptions that tend to be enforced by the participants themselves through internally and externally imposed costs and inducements.” Not all too different, for Vatn (2005, p. 63) norms “..combine a certain situation with a required act or solution which supports an underlying value”. He considers them to be the “..archetypes of institutions in civil society” (p. 64).

The scientific discipline closest to the socio-economic issue of the management of resource peaks is economics. However, the related sub-disciplines, environmental economics and resource economics, are both based on orthodox neoclassical theory. Both insist on the market as the only and most effective institution for managing GNoRK resources. This idealisation of the market has its roots in Adam Smith’s “invisible hand theorem” (Smith 1776), and they have indeed proven very efficient for allocating certain goods (and some renewable resources) if property rights exist and are clearly defined. However, markets are not suitable for addressing *distribution* issues. Distribution is considered optimal (Pareto optimal) from the beginning, i.e., before trade happens. In the case of GNoRK resources, there is both a spatial (i.e., geographic) and a temporal (i.e., intergenerational) distribution problem. The former would be referred to as the comparative advantage of the country that happens to own the resource. The norm and formal rule of property rights to land (extended to what is underground) within national boundaries are an institutional precondition for the legitimacy of trade in GNoRK resources.

Intergenerational justice, on the other hand, is not seen as a problem due to the orthodoxies’ (e.g.: Barnett and Morse 1963) rejection of absolute scarcity of resources. Instead it is insisted that any resource will only be scarce relative to one another, or a different (lower) quality of the same resource (Daly 1992a). Advances in science and technology are supposed to overcome this obstacle by making them more homogenous. We on the contrary are convinced, on the contrary, as argued by ecological economists (e.g. Daly 1992a),that low-entropy matter/energy is scarce in an *absolute sense*. Since there is no substitute for low-entropy matter/energy, to raise the relative prices of all of these resources would merely increase the absolute price level and cause inflation. In other words, price increases of GNoRK resources, which are difficult to replace, could instead of evoking the development of alternatives result in inflation and a perpetual economic downturn (Daly 1992).

Karl Polanyi ([1944] 2001) further argued that there was an inherent problem involved in the commoditization of labour and land (which he argues is just another word for nature). According to Polanyi, it is against their "nature" to be reduced to a commodity, as they are not produced by man in order to be sold. As acceptable as it may be to our society to buy and sell land, nature is something that cannot be owned in many cultures and indigenous tribes. Often it is sacred and has to be treated with respect for those who come after. Here, we argue that such a commoditization is further based on the acceptance of the norm of the "rule of the jungle" i.e., the bigger eats the smaller. Those who have the purchasing power are entitled to whatever they want for whatever purpose, even if others end up not having enough for survival. We also argue that the commercialisation of nature and resources has lead to the loss of some notion or norm of "respect".

Moreover, markets are not able to capture the complex qualities of natural resources and thus represent a vast simplification of human interactions with nature (Vatn 2005). In line with the neoclassical paradigm, it has to be assumed that everything is known either with absolute certainty or in the form of some probability distribution (Georgescu-Roegen 1971 ch. 5-8; Edmonds and Reilly 1985; Perrings 1987). Furthermore, the interaction between the economy and the environment is expected to proceed in infinitesimal, qualitatively identical and reversible steps without the consideration of possible thresholds or points of no return. In reality, "of course, all real economic (and other) processes are irreversible" (Söllner 1997 p. 181, own emphasis). In the case of GNoRK resources, it is highly uncertain what shape their depletion curves have, which is critical for managing resource peaks. There could be sudden unexpected tipping points, which are almost impossible to predict with enough precision because of all the irregularities and uncertainties involved in the data. Moreover, peaks of GNoRK resources are highly interrelated. Peak P, for example, is dependent on Peak-Oil and – less so – also the other way around. The same is true for other GNoRK resources such as metals and other minerals, but also for many renewable resources such as fertile land (peak soil), water, etc. To name but one such example: increased water shortages all around the world will increase the demand for water from desalination plants, which are powered by gas and hence increase the demand for and depletion rate of gas.

Finally, we identify *technological optimism*, which seems to act as a reinforcing and 'gap-filling' mechanism in neoclassical economic theory, as another dominant norm in the institutional management of GNoRK resources. It facilitates both the assumption of factor substitutability (i.e. the rejection of absolute scarcity) and the assumption of reversibility. In fact human technological progress appears to be a panacea for mainstream economists. This optimism is by no means substantiated (Aage 1984) as the laws of thermodynamics will always impose limits.[25] Hence it is argued here that it will be difficult if not impossible to replace GNoRK resources such as petroleum and P, in the quantities and for the "price" at which we are consuming them today.

2.5.8 Formal rules

As emphasized by Bromley (1989), in the case where resources issues (access, property rights, etc.) have a high potential for conflict, legal relations are fundamental to creating order in societies. Vatn (2005) agrees, arguing: "If resource uses are competing, as is dominantly the case with environment issues, the distribution of rights becomes a core issue" (p. 13). Vatn (2006) defines these formal rules as combining "a certain situation with an act that is required or forbidden and which is governed by third-party sanctioning" (p. 65). According to Bromley (1989), this third party would have to be a court system within a state. However, since in the case of GNoRK resources we are dealing with a global issue, there is no such third party that would have a power comparable to that of the legal system within a state.

Although international agreements do exist, it is often argued that the international community lives in a state of anarchy (e.g., Vatn 2005). There is no common normative authority to establish or enforce such rules. However, the sovereignty of a state over the resources that lie within its national boundaries (and do not move like fish) is widely accepted and the violation can also be punished by the military forces of international alliances (e.g., Gulf War I). Hence this causes friction only where national boundaries are disputed. Nevertheless, these boundaries are often more than arbitrary as they are basically social constructs and thus prone to friction (Vatn 2005). In many developing countries they are the result of the rule of the colonial powers who divided the land amongst them. Colonialists "legally" obtained the property rights of the land by "exploration" and force. Still today it could be argued that many nation states are actually not free to decide over their resources, as they are often not free to "not sell" on world markets for market prices. There is pressure from organisations and countries which they are indebted to (e.g., World Bank, IMF, World Trade Organisation) to open their markets to foreign investment. After that moment it is again the

[25] Of course, physical laws have been found untrue in the past, but according to most physicists, among them Albert Einstein, the laws of thermodynamics are the least likely ever to be overthrown (Daly 1992a).

norm of "purchasing power" that rules. International resource extraction companies will move in, after having received the licences from the authorities (which are often corrupt and not legitimate) and deplete the stock. Those countries that are not willing to play "the market game" face the danger of being boycotted or even attacked militarily as has been the case in the past (compare the case of Cuba, Angola, etc.).

However, even if nation states had entire freedom over the resources within their national boundaries, this may still be a formal rule (or norm) which could be criticised on the basis of human rights. Firstly, there is again the problem of intergenerational justice: Since non-renewable resources are per definition unavailable for future generations after their depletion, who gives present generations the right to impoverish their descendants? Natural resources are in fact part of a country's capital (which means that the revenue from selling them is actually not a profit according to accounting rules). This problem has been addressed partly by El Serafy's[26] rule. However, returning to the dominant norm of neoclassical economic theory: technological optimism allows assuming that future generations will be better off than present ones due to continuous economic growth and new inventions to facilitate life. Although natural capital is used up, we leave behind man-made capital, which is assumed to be a perfect substitute for the former.

In addition, one could ask the question whether it is really fair that some actors (nations) should control resources that everyone needs. The formal rule of property rights to land is a social construct, and while deeply embedded into Western society's conventions and norms, it raises the question of global resource equity. Economic theory also offers a good explanation of why the current situation is problematic. The concentrated resource endowments of certain countries put them in a position of monopoly or oligopoly power. The OPEC countries offer a good example for the latter. Unlike anti-trust authorities within nation states, there is no institution that could control such a situation. These leaves the international community only two choices: find alternatives or oppress/control resource owners in case these actors do not play a "fair"[27] market game (e.g., the US controlling the Western Sahara resources via Moroccan military power).

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[26] See Glossary of Terms.

[27] What is fair or not is obviously up to the parties interested in the resource. The general norm would probably be that it is fair to sell with an "acceptable" mark-up over EER costs.

Alternative models to this dominant paradigm of property rights could be based more on ‘human’ rights. That is, resource ownership or allocation not based on land ownership by nations or individuals, but rather on a ‘resource per capita’ basis for such essential resources as energy, phosphorus or water. Young (2007) even postulates a future model on a ‘per livelihood’ basis. Of course, to change and administer such a system would pose significant challenges; however, the point of this argument is one of ethics and dominant norms behind current practice and conventions.

2.5.9 Outcomes

One additional issue should be mentioned here with this regard, as was argued by Vatn (2005): the rights structure influences resource use. Nation states which have a large stock of a resource have no interest in any attempts to reduce world-wide consumption of that resource, as they have much more than what they ever could use themselves. On the contrary, they might have so much that they are afraid they will not be able to capitalize on the resource before a substitute is found (influence of the norm of technological optimism and relative scarcity). Saudi Arabia for example, is seen in most occasions as hindering progress in any UNFCCC agenda item that might affect oil consumption, insisting on compensation for oil producing countries for the effects of climate change measures, and holding some agenda items "hostage", as it's the case with bunker fuels (emissions from international aviation and maritime transport) (Muñoz, 2008).

2.5.10 Feedback loop between outcome and institutional response

This section refers to institutional change, or lack thereof. It is clear that the resultant outcomes from the action arenas are business-as-usual, or at best, some ecological modernization, in line with the ideologies and motivations of the powerful agents and dominant institutions. So what would it take to ensure more appropriate governance?

One possible institutional barrier to creating adaptation policies, in addition to the interests of the most powerful agents, is ‘lack of fit’ (Young 2005). Young here refers to the mismatch between a biogeochemical cycle and the institutions governing it. This is apparent both in the case of oil and phosphorus, and can be applied to GNoRK resources more generally. In the absence of any powerful overarching and coordinating agent or institution concerned with the sustainable management of GnoRK resources, the dominant institution – the market – will prevail. The market is not interested in long-term sustainability. The rate of change of global biophysical systems (here, oil and phosphorus) is too slow to be picked up by the market. And in the case of the rate of change of the global phosphorus cycle, it is also below the radar of almost any political or public arena.

However, these systems will eventually reach a tipping point (a peak production in the case of oil and phosphorus), where the biophysical change is too fast for the 'sluggish' institutional change to keep up in a timely manner. This lack of adaptive capacity or 'resilience' in the system makes it more susceptible to sudden shocks or changes (Stockholm Resilience Centre 2007). The vulnerability of these systems is magnified by the apparent lack of institutional diversity (i.e., the market system being the dominant regime).

2.6 Findings

While the notion of increasing oil scarcity appears in both the academic and public arenas, the phenomenon of peak oil is still only an accepted discourse in some academic spheres and interest groups (such as the ASPO). For phosphorus, both the issue of absolute depletion and peak phosphorus generate little attention by academics, politicians, and society at large.

Furthermore, there is no coordinated regime or institution consistent with the attributes of GNoRK resources. Similarly, there are also no appropriate agents with enough power to institute appropriate policies and institutional change. This is more so in the case of phosphorus, which has no agent at all responsible for the global phosphorus cycle. Thus, the phosphorus cycle is a 'homeless paradigm' (Cordell 2006), or fragmented (Young 2005; Young 2007), in that there is no single obvious or intentional agent or institution responsible for its governance.

We identified the market as the most dominant institution for managing GNoRK resources and also made clear that it is not fit for this purpose. Markets cannot address distributional issues at a global and intergenerational level nor are they suitable for dealing with absolute scarcity. Moreover, it was made clear that the complex attributes of GNoRK resources in an extended notion of land are ill-suited for commoditization and thus for being dealt with on markets. The neoclassical framework is the overarching norm that delivers justifications and reason for this sole focus on markets.

The dominant formal rules, which mostly serve to uphold the reign of markets, are property rights of land. Nation states have in theory sovereignty over the GNoRK resources situated on their territory. This creates a series of ethical (intergenerational justice) and market technical (oligopoly and monopoly power) problems.

Finally, we found our definition of global non-renewable key resources (GNoRK resources) very useful and appropriate. The two cases we discussed – that of oil and that of phosphorus – fit very well into this description, despite their different attributes. Throughout the analysis it became evident that most conclusions made about the management of the peaks of oil and P can be equally applied to other GNoRK resources.

2.7 Appendix I: Stakeholder analysis tables

Agent	Interest -- - 0 + ++	Power 0 + ++	Comment
INTERNATIONAL			
IEA (International Energy Agency)	-	0	It is itself subject to inertia and seems not willing to change direction or make any (radical) normative assertions. It is heavily influenced by the interests of its member states.
OPEC (Organisation of the Petroleum Exporting Countries)	--	+	World oil prices depend on the extraction quota they agree upon. However, nowadays they tend to bow to international pressures. A high oil price is in their interest, which means they also do not want the quotas to be too high. However, they have a strong disinterest in any international moves towards reducing oil consumption (boycott of Kyoto and UNFCCC).
ASPO (Association for the Study of Peak Oil and Gas)	++	0	Scientific think-tank which is largely ignored even in the academic community.
Oil companies	-	+	They know they will harvest large profits as oil gets scarcer. Hence we allege they focus on depletion and avoid mentioning peak oil. Their power rests for example in their ability to suppress data, but their economic/lobbying power is also significant.
NATIONAL			
Other net exporters	--	+	Some, where oil exports are less important for their economies, may be inclined to support institutional change: e.g., Ecuador recently decided not to exploit a potential oil field due to protests of indigenous people.
US	-	++	Interested in maintaining hegemony and current heavy resource use based economic system (as it is the "master of the game" and controls access to most of the oil, if necessary with its enormous military power)
Europe	0	+	Lack of military power to match the US and hence control, but still does not make any drastic moves as it is also heavily involved in the "market game".

Table A1: Agents' power and interest in institutional change and better governance of peak oil

2.8 Peak-Oil the very latest: Quick Summary of My Main Personal Take-home Messages from ASPO 2012 Vienna[28]

Posted by Luis de Sousa on June 28, 2012 - 3:44am:

This is guest post by Christian Kerschner. Christian is a PhD Candidate of the Institute for Environment and Technology (ICTA) at the Autonomous University of Barcelona and a Researcher at SERI Vienna. In his PhD he focuses on a multi-method analysis of Peak Oil, mainly using Input Output Approaches. Moreover, he published scientific articles on the steady state economy and degrowth. His latest work centres on attitudes towards technology.

ASPO is a no-budget loose association of people interested in studying Peak Oil. It was formed in 2002 (10th anniversary this year) by Colin Campbell and Kjell Aleklett, both petroleum geologists. The term Peak Oil (which often creates confusion - I don't know how many times I had to say "no, not Pig Oil - Peak Oil") by the way, was "created at that moment". They thought that ASOP (Association for the study of the Oil Peak) did not sound so good, so they changed the word order. The community meets yearly and consists of scientists and analysts /consultants. All speakers are on invitation only and there are mainly plenary sessions. Many speakers are contributors of the community's main communication platform, The Oil Drum, a high profile, quite strictly edited blog and one-stop-shop for everything related to Peak Oil (PO).

The conference was organized extremely professionally and had top sponsors and speakers:

Sponsors

- Austrian Environment Ministry
- Ministry of Traffic
- Innovation and Technology
- City of Vienna
- The province of Lower Austria
- Austrian Chamber of Commerce (WKO)
- Austrian Energy and Climate Fund

Speakers

- Politics
    - 2 Austrian Ministers (Pernkopf and Berlakovich i.V)

[28] published: http://www.theoildrum.com/pdf/theoildrum_9251.pdf

Vice mayor of Vienna (Vassilakou) Christoph Chorherr (Green Party President Vienna) Yves Cochet (EU Parlament member)

- Science
    - Robert Hirsch
    - Dennis Meadows
    - Helga Kromp-Kolb
    - Nebojsa Nakicenovic
    - Wolfgang Streicher
    - Werner Zittel

All presentations are no the conference website http://www.aspo2012.at/.

The following represents a bullet-point style summary of my main take-home messages.
Content:

- Main drivers/issues for Oil and Energy at the moment
- The state of the Peak Oil Debate in ASPO today
- The lack of appropriate official institutional and policy response
- Possible Impacts
    - Climate Change: Helga Kromp-Kolb
    - Geopolitics: Michael Klare – Resource Wars
    - Financial - Monetary System
- Solutions are easy
    - The golden age of Shale oil (Schiefer gas)
    - Renewable Energy (RE) affluence vs. sufficiency
    - So if it's so easy, why is it not happening already?
- Solutions are difficult but possible
    - Systemic-Change, Collapse, Economic crises, End of Capitalism
    - Reiner Kuemmel: Thermodynamics Entropy and the Origins of Wealth
    - Nate Hagens

Main drivers/issues for Oil and Energy at the moment

- Arab Spring (supply disruption)
- Fukushima (higher fossil fuel demand by Japan),
- 2011 first year in history with oil prices above 100 US$/barrel on average,
- 2-5 Million barrel/day decline of supply per year,

- the world in recession, OECD countries consuming less - all and more absorbed by India, China, etc. (10% growth = 1-2 million barrels/ year more)

The state of the Peak Oil Debate in ASPO today

A nice summary of the main discussion points was presented by Paul Hohen:

- Peak Oil is now! (true but there is some delay due to unconventional oil and gas)
- Plateau Oil now! (true, since 2005 at just above 80 Mb/d, but not for very much longer as the potentials of unconventional oil and gas are extremely limited)
- The precise moment of PO is not so important anymore, as we are probably already at or closely before the peak according to many. (Robert Hirsch: Peak is likely in 1 to 4 years).
- Peak Myth (i.e. there is plenty still): not true - good news trump bad ones - new finds exaggerated (e.g.: shale gas hype)
- Peak Demand: (False - demand is still rising, especially in Asia. As Bob Hirsch says - there is a 100 trillion US$ infrastructure installed on the planet which works on oil - changing this will take many years - 20 or more).
- Peak Price (or Peak Economics): (also true but there is a maximum price the economy can take before it goes into recession and the oil price falls – 6-7% of GDP according to Euan Mearns). Price should not be overemphasized - according to Meadows - the main issue is Exports! For producers of oil the market price is not that relevant.
- Peak Emissions: (True? IPCC seems to overestimate available hydrocarbons for its scenarios (only 3 of 37 are within realistic ranges according to Aleklett), but there are other drivers for green house gas emissions too). According to Nakicinovic, there is still 30000 Gt of C02 in Coal left. Only 850 are allowed to remain below 2 degrees.
- Peak Insecurity: Political insecurity is on the rise, which explains the rush of the oil industry to invest in shale gas/oil which is technically difficult but in politically safe places, where they can own assets.

According to Hohen, the main Analysis Gaps are:

- Information (lack of reliable oil data)
- Awareness (politics, business, investors, media, consumer)
- No structured discussion (IEA denies PO)
- Communication: not attractive for media - bad story with no happy ending
- No official policy response

The lack of appropriate official institutional and policy response

The reasons why politicians do not want to touch PO are mainly two:

- Jeremy Leggett: There is nothing of interest in PO for a politician - if in opposition - (s)he will be attacked for scare-mongering; if in office - unraveling an issue for which one cannot present credible answers is political suicide.
- Robert Hirsch: Politicians react only to what is there as people prefer to deal with problems of today, not with those of tomorrow. Peak Oil is a very bad news story that people don't like. The climate change story on the other hand has been communicated better - everyone can do something about it. With regards to PO we have failed. I am not sure what we should do.

This of course would explain why official statistical bodies (IEA & EIA) are put under pressure, not to unpack the issue publicly. If someone "important" would use the word Peak Oil publicly that would cause chaos and confusion on the markets.

Rainer Kummel: Politicians are smarter than the general electorate. They know about Peak Oil. But if they would propose any measures the tabloids would beat them.

Michael Cerveny: People are made to believe that high oil prices were due to speculation. Hence many think it was a temporary phenomenon. Now SUV sales are going up again. And people continue to install oil heating systems. Policy makers should warn people that high oil prices are here to stay.

Another problem is mainstream economists, who advise governments and politicians. They insist that there are no risks and that there are still 40 years of supply (Jeremy Leggett, UK industry task force on PO). According to one UK secretary of state, tar sands still offer vast amounts of oil. When Jeremy asked, if he/she knew about their actual flow rates, he/she replied: We are economists, we don't do such details. Moreover Jeremy reports from a secretary of state which first agreed to an oil shock response plan, but 6 months later denied everything.

Possible Impacts

Robert Hirsch: Important: Peak Oil is not an energy crisis but a liquid fuels crises!

There will be many similar phenomena to those seen during the 1970s oil crises: lines at the petrol station, public anger, rationing. People will be in pain.

Climate Change: Helga Kromp-Kolb

We should stop talking about % decreases of emissions. It's the absolute numbers that count! Even 2 degrees temperature rise may be too much for tipping points. 1,5 would be better - but both are below most optimistic IPCC estimates. Changing that is said to be economically not feasible - but a safe operating space for humanity is more important than temporal economics.

Geopolitics

Michael Klare presented a very gloomy outlook for what's going to happen in his book "The Race for What's Left: The Global Scramble for the World's Last Resources". He explains the Oil factor behind wars - from WWI and how the "Carter Doctrine" justifies US military intervention if the free flow of oil from the middle east is in danger. This discourse was quite open until the campaign "no blood for oil" with Bush I. Then however the discourse changed to that of weapons of mass destruction and fighting terrorism. Another speaker - Daniele Ganser - said there were people who therefore doubt the official 9/11 story.

According to Karin Kneissel - WWI is still not over. The territorial fragmentation continues. Borders in the middle east were drawn according to pipe lines. Nevertheless, future resource wars are not going to be located there, but in the South Chinese Sea, where large gas fields are. There is a certain sentiment of the revenge of the colonized against the former colonizers. China is much faster in securing resources. Europe took 10 years trying to reach consensus over building the Nabucco Gas-Pipeline and failed. The Chinese on the contrary just built a 8000 km pipeline in only 11 months.

Resource Nationalism is a useless concept which does not explain the increasing control over natural resources according to Olivier Rech. Moreover it a dangerous concept, as it sounds like countries should be forced to share their resources freely. Different cultures have different ways of viewing intergenerational equity. In the US, UK and the Netherlands for example individualism is dominant - not so in Saudi Arabia - where decisions should be taken for the good of the community.

According to Alexander Pöegl, oil markets are manipulated purposefully by the super powers:

- If oil prices too high - "we release strategic reserves" - gives an impression of safety.
- Too low - FBI issues warning over .....

Financial - Monetary System

A wide consensus emerged that the financial system will inevitably collapse, because outstanding debts are borrowed future growth, which will not happen anymore as it was fueled by cheap resources. Fiat money is no longer working if energy prices increase constantly. Hence many European countries are now printing money for buying the oil they can no longer afford – the EURO crises being a direct effect of the oil crunch.

Fiat money is no longer working if energy prices increase constantly. Many European countries are now printing money for buying the oil they can no longer afford.

Nate Hagens: Money is created through loan. This wasn't a problem before. Money was scarce and there were many opportunities; now this has changed. Debt is a reallocation of resources over space and time: from the periphery to the center and from future to present generations. Now every dollar of debt produces only one dollar or less. The problem is that standard economists thought that oil would behave like any other product - become cheaper and cheaper. Without debt we would be in recession since 2008 - what we do now will make the fall sooner and steeper - debt speeds up extraction process.

One possible remedy for one part of this problem was presented by Thomas Bachheimer (Gold Standard Institute): The big problem is that we have limited sources of oil (energy) and an unlimited yardstick to measure it i.e. US$. The amount of the latter is increasing, while oil is decreasing. Instead Oil should be traded in gold as no other commodity is relatively so stable. At the moment we have the unacceptable situation that the US as the only country in the world can print money to buy oil.

Solutions

Thinking about solutions is the main challenge for ASPO according to many of the present speakers and participants. The Association was formed to warn about Peak-Oil not to present solutions. If this does not change quickly ASPO will remain publicly irrelevant (just like the Club of Rome) according to Meadows.

"Prediction is difficult especially about the future!" (Niels Bohr)

Solutions are easy

The golden age of Shale oil (Schiefer gas)

This is not a golden age, but the retirement party of the oil age (Arthur Berman). "If something sounds too good to be true, it probably is."

The industry is losing money with it (Arthur Berman), because the wells are extremely expensive and have very fast decline rates (Euan Mearns). This is particularly the case since gas prices in the US have collapsed. Temporarily some good wells may still be subsidizing bad ones.

Disadvantages of shale gas:

- Fast decline rates
- Expensive wells & technology
- Danger of groundwater contamination by chemicals added to fracking- water (2 tons per well!)
- Large land-mass necessary, because many boreholes necessary - this is a problem for Europe, which is much more densely populated than the US

Renewable Energy (RE) affluence vs. sufficiency

Obviously everyone is in favor of renewables, but there is big tension between those who preach "100% renewable is possible without radical systemic changes" (Jeremy Leggett, Peter Droege, Karen Smith-Stegen, Claudia Kemfert), and those who only see a limited scope for RE of around 10% of the current energy mix and therefore a need for (and desirability of - Hagens) sufficiency (Nate Hagens, Pierre-René Bauquis, Yves Cochet, Jeremy Gilbert, Rob Hirsch, Meadows, Reiner Kummel). Austria, for example, has a strategy to become Energy autarkic by 2050 including a complete restructuring of the energy system and Electricity autarkic by 2012 according to the ministries. Berlin for example is apparently already Energy-independent (Peter Droege). Wind alone, so it is argued by another speaker, could provide 4-5 times global conventional energy demand. Berlin is already Energy-independent (Peter Droege). To many (e.g. Michael Klare), RE are the only hope for avoiding collapse and resource wars.

The middle ground of these positions is covered by Nakicenovic's idea of "transition", driven strongly by efficiency and maybe Wolfgang Streicher's "100% Renewables for Austria by 2050" (the study does not include the Rucksack of imported goods which amount to about 44%). On the technological side of renewable Audi is currently working on combating the main problem of RE - cyclicality, with its system of power-to gas conversion (Hermann Pengg).

Pierre-René Bauquis is the only one in favor of Nuclear due to the limited scope of RE. Even though he claims that with solar energy we might have a "wild card", as progress is difficult to predict. Total (which he worked for) is still the only oil company which openly talks about Peak-Oil. Gilbert and Hirsch would be among those being in favour of more exploration of fossil fuels. Hirsch would also be in favour of pushing Coal-to-liquid. Gilbert calls the media and public reaction after the Gulf of Mexico an exaggeration (new technology inevitably has risks and costs - if we want more oil we have to accept that). The Rimini (oil cap) protocol, which he recalled himself, is an unrealistic dream, as we do not want to reduce our consumption voluntarily.

Not surprisingly, many "100%-no-problem people" have vested interests in the renewable energy industry or work within the framework of such projects (e.g. Smith-Stegen for Desertec , which is according to critics - despite the good intentions - solar colonialism - this caused quite some debate).

So if its so easy, why is it not happening already?

The answer given throughout was the huge power of the oil lobby, which is interesting, as many people at the conference work or have worked for that industry at some point (insiders). The energy industry, the incumbency, works hard to keep us in the fossil fuel age in order to keep power production centralized says Jeremy Leggett for example, The hope/assumption of many (e.g. Aleklett) is that a new energy system will be democratised. This however is exactly what "Big Oil"does not want. So every new small find of oil or shale continues to be celebrated like a new Quatar (The Economist: Drowning in Oil).

Fossil fuel subsidies are still 312 Billion US$ compared to 57 Billion US$ for RE (Claudia Kemfert). A major problem of the renewables industry and for investors is that banks don't provide loans at acceptable rates.

Solutions are difficult but possible

Systemic-Change, Collapse, Economic crises, End of Capitalism

Even though the IMF just reaffirmed that high oil prices have nothing to do with the economic crises, many of the most prominent speakers agree that PO is a major game-changer and means the end of Capitalism at least in its present form.

Meadows compares the economy to a race car which goes at 200 km/h. Taking off one tire does not mean it will go at 150 km/h - it will not go at all. The economy cannot take an oil price of above 200 US$ - it will collapse. The Eurocrisis to him is due to high oil prices.

Euan Mearns: Capitalism is based on cheap fossil fuels and a free licence to pollute. Both are changing now, being the death knell of capitalism - the fall over the net energy cliff. It is clear that the economy can only take certain levels of oil prices. If it's more than 6-7% of GDP, then the economy goes into recession.

Reiner Kummel: Thermodynamics Entropy and the Origins of Wealth

According to the cost-share-theory the energy sector has no importance as it only represents about 5% of costs. Hence only capital and labour were included in the production function. This neoclassical cost-share weighting always resulted in a 0,5 % residual (Solow residual), which is traditionally attributed to technological progress (liker manna from heaven). In fact only 50% of GDP growth can be explained that way. Professor Kummel produced a model (KULEC model), with which he shows the true contribution of the Energy sector to the productive powers of Germany (almost more than the other factors together: capital, labour and creativity).

He concludes: Energy is cheap and productive while labour is expensive and "unproductive", which explains why the latter is replaced by the former wherever possible. Wealth goes to those who own, control and use resources. He is critical of the "Energiewende" as hasty decisions could lead to dirty outcomes. He proposes most of all taxing energy instead of labour.

Petro Prieto: But that would cause capital flight, energy should be taxed globally. Kummel: Yes but thats even more difficult.

Nate Hagens

Energy Slaves: It takes a human being 11 years to provide the same amount of energy contained in one barrel of oil. Energy is the largest driver of economic growth - more than technology.

A lot of consumption is due to status - the peacock-phenomenon. The problem with easy solutions (i.e. renewables, electric cars, etc.) are the externalities e.g. high water footprint of electric vehicles. The current economic activities make it difficult to satisfy important human needs: being social, empathy ... A lot of consumption is due to status - the peacock-phenomenon. We should work to consciously change that, which however is difficult – similarly to telling a teenage girl to dress ugly.

On pessimism vs. optimism, he argues that the former is a kind of cowardice, as it often implies no action. He is pessimistic about our current economic system, but optimistic about what comes after. Less does not have to be bad. A systemic alliance is needed. We know if 10% understand this well the rest follows very quickly (critical mass). He used to be a Wall Street broker and earned lots of money, he now has spent most of it, owns a house in the countryside, spends a lot of time gardening and with his dogs .... is happy. It should not go unmentioned that this last presentation received by far the longest ovation of all.

3 Concepts and Theories

3.1 Our Energy System and the coming Energy Challenge

The industrial revolution, that generated our modern life style, was possible because of the plundering of concentrated stocks of fossil energy. In the next century, the most developed economies learned how to harness an incredible amount of power by relying on a massive use of a diversified mix of fossil fuels. In this way they moved into a post-industrial phase of economic growth associated with a total globalization of the economy. The absolute dependence of modern societies on fossil energy is a serious reason of concern. In fact, the on-going depletion of fossil energy stocks (Peak Oil) implies that we can no longer assume as granted that in the future it will be possible to keep increasing at will the amount of energy we consume. This problem does not refer only to oil, but also to other key fossil energy resources.

Because of the historic concern for the non-renewability of fossil energy, modern societies have always engaged in a systemic quest for a “Magic Bullet” or the “Philosopher’s Stone” in energy terms, a source of energy which would guarantee an unlimited supply of energy. In the 50ies, the “nuclear age” was announced and it was proclaimed that electricity would soon be “too cheap to meter”(Strauss 1954). After 50 years of experience it is becoming more and more clear that nuclear power is still more expensive than oil, with a series of problems which are not fully resolved (Diaz-Maurin and Giampietro under review).

Next on stage was the idea of The Hydrogen Economy, publicized by Jeremy Rifkin (2002) and others. A good example of wishful thinking assuming that it will be possible to dramatically change the various processes operating the energy sectors, while keeping current economic structure unaffected. Moreover, hydrogen does not belong to a discussion about Primary Energy Sources (Our Energy Future 2010) as it is merely an Energy Carrier like batteries. This means that hydrogen still requires a primary energy (wind, nuclear, etc.) to be produced.

After hydrogen came biofuels (or better Agrofuels), which found strong political support, until one very obvious impact of biofuels became widely known: burning food for fuel means less food to eat for people (Giampietro and Mayumi 2010). When excluding fossil energy and nuclear energy, at the moment, the remaining mix of various sources renewable energy only counts for less than 10% of the total in most countries. Fossil energy has a mix of qualities that unfortunately alternative energy sources, so far, do not have. However existing alternative sources can be competitive when used within a different pattern of production and consumption of energy carriers. But if we want just to substitute the current pattern of production of energy carriers (based on fossil energy) with alternative sources, these alternative sources (but a few exceptions) will turn out to be more expensive than the conventional ones. This is the reason why a large fraction of alternative energy sources need subsidies to be operated.

3.1.1 Energy systems

An important argument made by energy scientists is that, since every system has its particular source of energy, the system will change radically once this resource declines (e.g. Odum 1971; Tainter, Allen et al. 2003; Brown 2006). This is to counter those who believe we can easily substitute oil and gas as major energy sources, with for example, shale oil, tar sands, nuclear energy or renewable energy (agro-fuels, wind, solar, geothermal, etc.). If the property of the potential new energy source is different in terms of its net energy (Odum 1971) or Energy-Return On Investment (EROI) (Hall, Cleveland et al. 1986), which is essentially the case for most alternatives to oil and gas that we know, then the human economic system is bound to change radically or even collapse

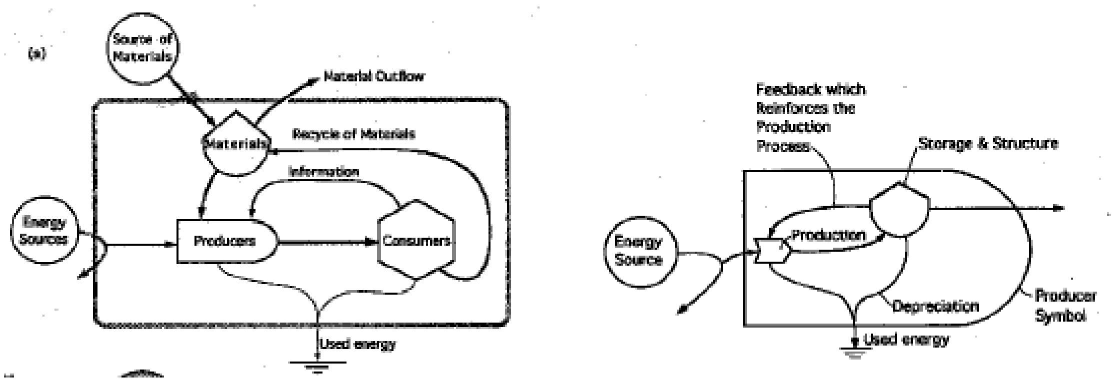

Figure 20: Odum's basic Energy Systems diagrams
Source: Environment, Power and Society, Odum (1971)

Moreover it is not possible to reduce the rate of energy flowing through a society while maintaining its actual set of functions without first operating a major rearrangement of societal identity. However, rearranging the identity of a society (as whole and in each one of its parts) can result very difficult, since biophysical processes, in general, show certain inertia against changes. In particular, human systems tend to express a strenuous resistance against any attempt to change its identity. This implies that for many reasons modern societies are locked into the existing pattern of use of fossil energy and will probably remain there for the next decades to come. The implications of this fact are worrisome, as we can expect that in this struggle to survive markets will be distorted and poor and marginal economies that are disadvantaged by the present system will be the most probable losers.

Many in national governments and in the general public seem to be sure that a rapid transition to a “low carbon” economy based on a totally different pattern of production of energy carriers is a viable option, which can be easily achieved by signing a few agreements. This fact is confirmed by the choice of ambitious targets – e.g. amount of reduction of CO_2 emissions and the timing for achieving these results – which are often discussed at international agreements (e.g. the Copenhagen summit).

As a matter of fact, from an energetic point of view, a dramatic reduction of energy consumption in a metabolic system should be considered a quite unlikely event. This means that even if humankind had the option to move to a lower level of consumption, it will be very difficult to obtain a dramatic reduction of energy consumption in our modern economies for a span of decades.

In theoretical terms we can say that self-organizing systems (belonging to the class of autopoietic systems = systems making themselves) are dissipative systems. They need a continuous consumption of energy in order to be able to express both organized structures and functions. For the expression of their own identity these systems tend to consume as much as possible energy, to maximize their diversity and adaptability (maximum power principle)(Giampietro and Mayumi 2008).

This basic principle also explains the so called Jevons’ paradox. Every time increases in efficiency make it possible to express either a function or a structure using less energy, the system will use the freed energy to explore new functions and new structures to be expressed (Tainter 2010). In modern societies the explosion of energy dissipation associated with fossil fuels has enabled the generation of an incredible complex society expressing millions of different organized structures and functions (Tainter 2000). This leap forward in energy dissipation has been possible thanks to the very high quality of fossil energy. Therefore, it is not clear whether it will be possible to retain all the existing structures and functions when reducing the quality and quantity of our primary energy sources.

In the last two centuries the massive production and consumption of energy carriers resulted in the establishment of a set of gigantic infrastructures, which represent a formidable lock-in for dramatic changes in energy uses. But even more important is the lock-in which is generated by the existing political power structure. Political and military power guarantees the access to resources of energy, which in turn make it possible to stabilize the existing political and military power (Goodstein 2005; William 2005; Elsayed and Elrefaai 2008). At the global level we see that more and more military conflicts arise due to disputed rights of access to oil, gas or other valuable resources. On the micro level we witness the same tendencies. Energy companies nowadays depend more and more on a reliable and expensive set of infrastructures, which is unavoidably associated with a pattern of centralized production and distribution of energy carriers. In many countries it is for example difficult (if not impossible) to develop an alternative distributed supply based on small, independent, local producers of electricity because of the resistance of large power companies (even if mostly state owned!). In this sense we can talk of an Institutional Lock-In, which can prevent the application of new energy saving technologies.

3.1.2 Debt and Energy

Another crucial side-effect of the availability of abundant stocks of fossil energy is that it has doped our economic systems by addicting them to debt (Douthwaite 2012). In fact, the possibility to expand the production of energy carriers at will (depending only on the demand) has boosted the effectiveness of policies making loans easily available. In this way, modern society learned how to constantly increase the consumption and production of goods and services in order to boost GDP. This mechanism generated a real addiction to economic growth, which is extremely dangerous. IF money is generated mainly as an increase of the existing debt, THEN it becomes impossible to repay a growing mass of debt when the economy stops growing. In relation to this point our whole financial system has been built upon the assumption of an unlimited possibility to keep the consumption levels of society expanding. All this is now beginning to shake as we approach the "after peak oil era", on the downward slope of the Hubbert's Curve. This new energy reality will force a re-shaking of the existing power relations among countries of the world and among social actors within individual countries; even though it is difficult to guess which factors will define success or failure.

3.1.3 Unemployment and Energy: energy surplus theory

Adopting an energy-analytical approach, one may possibly diffuse some fears about the coming economic and energy crisis and unemployment (e.g. Jackson 2009). Life is about capturing “net energy” or “surplus” as Marxists may say - whether from plants, animals or humans does not matter. It is about taking some of the extra solar energy, which the organism does not need in order to survive. Fossil fuels offer huge amounts of this surplus, because it originates from organisms which are long dead and no longer part of any ecosystem. However in order to make this surplus useable (as it cannot be eaten or otherwise applied usefully except for lubrication for example), we need machines. Technological advancement is largely driven by this situation. The surpluses we can capture from humans are much less than those from fossil fuels (and ethically problematic).Thus we can observe the on-going tendency of increasing labour productivity, by minimizing labour and maximizing capital investment in order to utilize fossil fuels.

This logic only works as long as the available amount of fossil fuels keeps increasing. Or to put it in very simplified terms: increases in labour productivity depends to a large extent on increases in available fossil fuel energy (and other non-renewable resources). In other words increasing labour productivity is an historic abnormality of the fossil fuel age and will change after peak oil, unless other equivalent sources become available (which seems unlikely). Hence in the medium to long-run, there will be no problem of unemployment, but rather the return of jobs which have largely disappeared during the age of cheap oil (e.g. in farming, crafts, etc.).

It is obvious, after understanding the terms of our energetic predicament that, in order to have change, it will be essential to develop wise energetic policies to be implemented as soon as possible. However there is a clear danger with most energy related policies.
Because, of a set of causes: (i) a systemic adoption of misleading narratives about our energetic predicament; (ii) a remarkable ignorance of basic energetic principles; and (iii) energy statistics still focused on old type of problems, which do not provide all the required information; we still know very little about the energetics of modern societies. This is a serious problem, since the implementation of energy related policies based on wrong analysis

can generate more harm than good for the issue of sustainability. For this reason, it is extremely important to start a systemic quality check on the narratives used when proposing policies in the field of energy. Approaches such as that presented in Part 2, are one of the many possible directions to take.

3.2 Some key principles of energy systems

The maximum power principle and its link to technological progress

„*In the self-organizational process, systems develop those parts, processes, and relationships that capture the most energy and use it with the best efficiency possible without reducing power.“* (Odum and Odum 2001, p. 70)

E.g. Trees with more leaves for catching sunlight displace lawn grass because of the support from trunks and limbs (consumers providing service to leaves).

To Georgescu-Roegen (1975) technological advances could be seen as mere attempts to use and employ (or waste?) the available stock of fossil energy at a faster rate (see also Part 3). Not only does technology allow us to extract resources faster, but also to find ever more applications for it (some of which utterly unnecessary)[29]. This is a process, which is certainly aided by the 'insatiability of wants' and the constant artificial creation of demand by sophisticated advertising techniques of the capitalist economic system. Fossil fuels in this view are a "historical and geological anomaly" and represent the sunlight of millions of Palaeolithic summers. Hence the current economic system, based on the high net energy contends of oil and with its huge amount of energy and material throughput is also an anomaly.

Joseph Tainter, in his book "Collapse of complex societies" (Tainter 1988) and also in later publications (Tainter 2000; Allen, Tainter et al. 2002), argues in a nutshell, that technological advances are not a sign of progress, but instead the result of an increasing societal complexity due to crises and scarcity. This for Tainter is the true reason, why there are still indigenous tribes, who still live the same way they did thousands of years ago. Only when population pressures lead to food shortages did man turn to agriculture and later the use of fossil fuels.

[29] Georgescu-Roegen liked to give the example of the "golf cart" as such a wasteful and unnecessary use of material and energy resources.

This was much more labour intensive and required more complex societies. Eventually, so Tainter (1988), the system becomes so complex that it cannot be maintained anymore with its limited (or dwindling) resource base. It becomes “too expensive” to run, which is the point in time, when it either collapses, or is successful in finding more resources. Sustainability for Tainter (2000) therefore does not mean “doing less of what we do” or using less resources. Instead we may need to use more or our society will lose its problem-solving capacity and collapse. Hence, at least for the short term, Tainter does believe in a technological fix and could to some extent also be categorized as a technological optimist.

3.2.1 Pulsing

Odum’s concept of systemic pulsing is very much related to the adaptive cycle theory of the resilience literature (see following chapter), except for the cyclical representation. Pulsing is a very interesting concept and affects all main topics of this thesis. It follows from the maximum power principle and argues that any energy system undergoes 4 stages: Growth, Climax, Decent and Low-Energy restoration. If the main energy source of a system is non-renewable, the next growth phase after the collapse will of course lead into a system, which is unrecognizably different to the one at the climax phase. Peak-Oil according to Odum’s arguments could not have been avoided, but the decent could be organised in a prosperous way (Odum and Odum 2001). He is therefore in disagreement with Helman (2011), who argue that such planned decent is not possible(Sorman and Giampietro in press) for the reasons mentioned earlier.

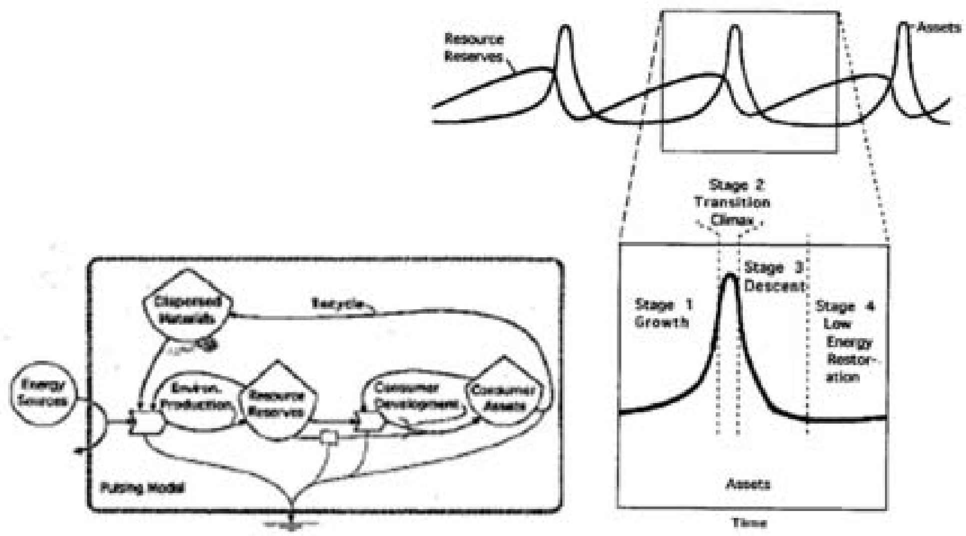

Figure 21: Pulsing Energy Systems
Source: Environment, Power and Society, Odum (1971)

3.3 Some methods for understanding energy systems (apart from Input-Output analysis)

3.3.1 Net energy analysis

(taken from: Our Energy Future 2010)

"A theoretical approach introduced in the 1970s, pointing at the need to analyze the entire set of energy conversions associated with a given energy flow or energy form. For example, when dealing with a Primary Energy Source, what is relevant is the net supply of Energy Carrier that can be used by a society, not the total amount of Primary Energy Source that is consumed. Net Energy Analysis can be carried out, for example, by using the concept of Energy Return On the Investment (EROI)."

3.3.2 EROI

(taken from: Our Energy Future 2010)

"Energy Return on Energy Invested (EROI) is one of the most important concepts in relation to the study of the quality of alternative energy sources, but also one of the most controversial. The concept of Economic Return on Investment – which inspired EROI – is an accounting valuation method used to assess the potential profit of a financial investment. In financial analysis this concept addresses at least two issues:

- the pay-back time of the investment; and
- the size of the required investment (input), which the investor must be able to handle.

However, very often, in energy analysis, the EROI is considered just as an output/input ratio determining a net surplus of energy, without considering the time dimension or the power level at which the flows are invested and supplied.

EROI is a semantic concept, useful for evaluating the quality of Primary Energy Sources. However, to implement this semantic definition one has to use a set of indicators and not just a simple ratio. In particular two factors should be considered when using EROI as an accounting evaluation method:

- the energetic burden associated with the conversion of a Primary Energy Source (PES) into a net supply of Energy Carriers (EC). This burden depends on the overall loss associated with two conversions: (a) PES to Gross EC and (b) Gross EC to Net EC, where the second conversion refers to the consumption of energy carriers in the production of energy carriers; and

- the power level at which energy carriers can be invested into the process of exploitation of PES. This is a crucial factor determining the final intensity of the net supply of net energy carriers to society."

The main author in the EROI literature is Charles Hall (e.g. Hall, Cleveland et al. 1986; Hall and Klitgaard 2011; Murphy and Hall 2011). For a critical appraisal see Giampietro, Mayumi et al. (2010). See Figure 22 below for EROI calculations.

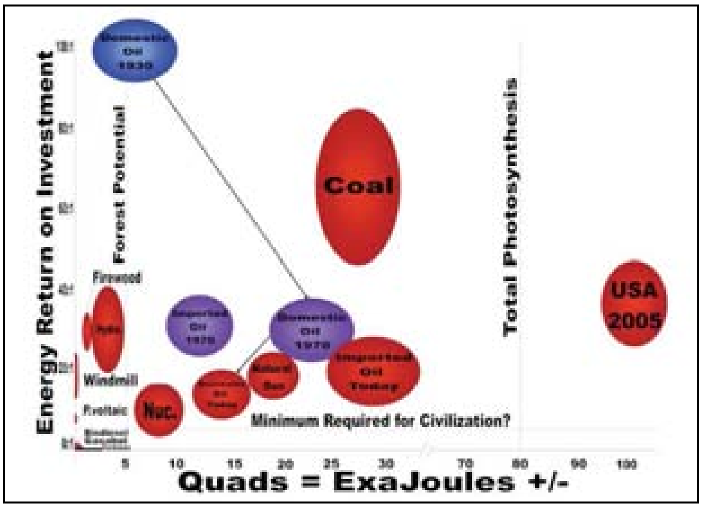

Figure 22: EROI of our main primary energy sources
Source: C. Hall, ASPO 2008

3.4 Resilience & Vulnerability[30, 31 *]

3.4.1 Resilience

3.4.1.1 Introduction

The term resilience is used in various scientific fields of research. Initially, it was being used in psychology in the 1950s, later also in ecology and economics. In psychology the concept of resilience is known since the 1950s and, ever since, this concept has become a well-

[30] Sustainable Europe Research Institute (SERI) Working Paper
[31] Translation German to English: Claudia Beisl and Christian Kerschner
[*] Corresponding author: Christian Kerschner, Sustainable Europe Research Institute (SERI), Garnisongasse 7/27, 1090 Vienna, Österreich; Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, 08193 Bellaterra, Espana;
e-mail: christian.kerschner@gmail.com;

researched area in the development theory of social psychology. Classical works dealing with these topics are, for example, Emmy Werner's *The children of Kauai* (Werner, Bierman et al. 1971) or Glen Elder's *Children of the Great Depression* (1999 [1974]). Not unlike the definition in other disciplines, resilience here refers to the ability of an individual to be emotionally balanced even though having encountered adversity, traumata, or significant sources of stress. This can be achieved by relying on individual as well as socially learned "resources".

In ecology the term resilience was introduced by Holling in his famous work of 1973 (Holling 1973). However, we may not forget that Mac Arthur already laid the foundation for the description of ecological "stability". Holling defined resilience as the ability of a system to absorb changes, and stability as the capacity of a system to establish equilibrium once a temporary disruption has taken place. He referred to this definition (1973) as "engineering resilience", as it is also being used in physics and engineering. Concurrently, the so-called „ecological resilience" refers to "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker, Holling et al. 2004, p. 1). Holling's work has laid the foundation for an active scientific community, the centre of which form the "Resilience Alliance", as well as the "Stockholm Resilience Centre".

The concept of resilience is of great importance in modern disciplines that deal with sustainability research (e.g. ecological economics), and systems theory, which is closely connected to it. It describes the tolerance and resistance of a system to disruptions and crises and is tied to growth and sustainability. Sustainable development, i.e. development that is environmentally friendly, commonly shared, in public interest, and adjusted to the shortage of resources, is only possible when ecological, social, and economic resilience are not endangered by human agency. As will be further elaborated below, this process is not about making a system more resilient, but about increasing and maintaining its adaptability and transformability.

Economic resilience also distinguishes between a static and a dynamic concept. The static concept is defined as the ability of an economic system to resist and absorb external shocks, loss, or damage (Holling 1973; Perrings 2006). The dynamic concept is defined as the ability to recover from a severe shock or crisis, and/or the speed at which the recovery is possible. In this context we may not forget about the systems theoretical assumption that systems intend to maintain their stability, even when they are subject to change that is against the will of the system's participants. Scientific research concerning economic resilience mostly belongs to the field of disaster research (management and prevention of disasters). Rose (2004) distinguishes between three levels of resilience: microeconomic resilience (behaviour of individuals); mesoeconomic resilience (economic sectors, individual markets, or cooperative groups); and macroeconomic resilience (all individual units and markets combined).

Closely related to economic resilience is **social resilience**. Adger (2000) defines "social resilience as the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change"(p. 347).

3.4.1.2 The "ball-in-the-basin" representation of resilience

The best explanation for the concept of resilience is the simplified „ball-in-the-basin" representation (see Figure 23). The small ball indicates the systems' current position. Its inherent dynamics drag the ball towards the bottom which could be seen as some kind of equilibrium that will never actually be established maintained over the long run. When sufficiently resilient, the system will not leave its basin of attraction during turbulences (shocks, crises, disasters, etc.). If this is, however, not the case, or if external influences are too strong, a system may be transferred across a threshold into another basin which is characterised by different qualities.

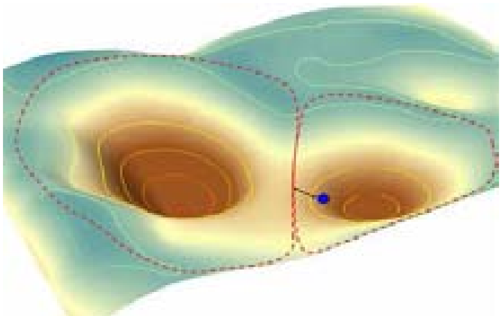

Figure 23: Ball-in-the-basin representation of resilience.
Source: http://www.resalliance.org/index.php/key_concepts

Ecologists and economists fear that such a new state of the system could be worse than the original state, from a human perspective. However, change does not necessarily cause deterioration. Psychology promotes the idea that facing and overcoming crises may definitely improve a person's overall condition. This assumption also holds true for socio-ecological and economic systems. Decisive variables in the economic system may change conceivably, due to the expected energy and raw materials crisis i.e the decreasing availability of cheap resources due to resource peaks. Despite this fact or even because of it welfare may improve, at least in the medium to long run. Of course, the contrary scenario may also happen. Possible preceding scenarios include manmade, substantial damage to ecosystems, or climate change (Peterson, Allen et al. 1998; Folke, Carpenter et al. 2004).

3.4.1.3 Adaptive Cycle Theory

Ecology assumes that eco systems are, in general, stable. If a system lacks stability, a disruption may, as already mentioned, cause the system not to return to its initial basin (Clapham 1971). Systems are, however, not static. As Carpenter et al. (2001) argue, they tend to pass through four recurring phases in their basin, so-called adaptive cycles (see Figure 24): the process of reorganization and renewal moves into a period of significantly growth, a sort of race for the “creative” use of plentiful resources (exploration). This is followed by a phase of conservation in which the most important resources diminish because they are bound in existing structures (or the supply of non-renewable resources decreases or ends). This leads to the next phase of creative destruction (as Schumpete would call it from an economics point of view) or a collapse which is quickly followed by a reorganization of the system and another phase of growth. The latter may take place in the same (or a different) basin of attraction, depending on whether the collapse of the system led to a crossing of the system’s threshold, or not. Fath (2012) introduces an alternative, and improved, image of the adaptive cycle (Figure 25). This figure is closer to reality, as the reorganization period in Figure 24 would otherwise be followed by another phase of growth.

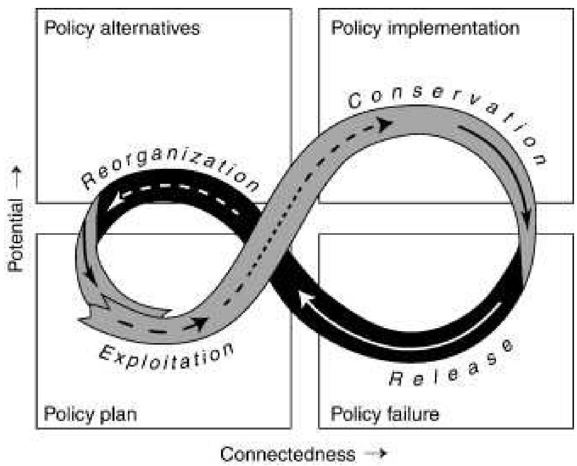

Figure 24: Adaptive Cycle Theory
Source: Carpenter, Walker et al. (2001)

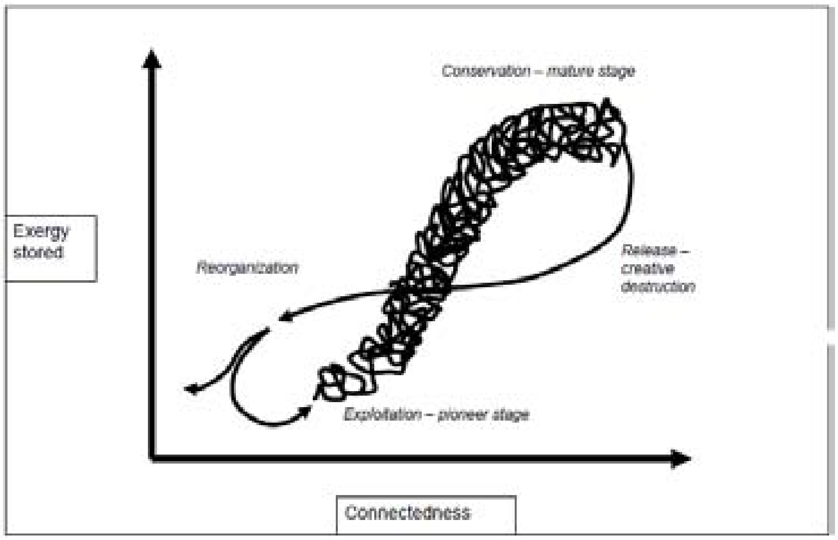

Figure 25: Adaptive Cycle Theory
Source: Fath (2012)

3.4.1.4 Socio-ecological systems (SES)

Ecological resilience has evolved into an interdisciplinary dialogue ever since the 1990s, first and foremost due to the works of Berkes and Folke (1998) and, later, Folke et al. (2002). Here, the human factor on eco systems is measured by means of an analysis of so-called socio-ecological systems (SES). These systems, social agents, and institutions that belong to them, are biological, geological and physical entities. Recent tendencies in resilience research can be regarded as an answer to the shift of political focus regarding sustainable development towards the economic pillar. A phenomenon which Hamilton (2010) attributes to the ubiquitous „fetish of economic growth". Nowadays the concept of socio-economic resilience has gained importance in international environmental politics. It played a significant role, for instance, at the famous "Millennium Ecosystem Assessment" initiative (2005) (www.millenniumassessment.org).

3.4.1.5 Panarchy

Due to the fact that sustainable development could be regarded as a systemic change, resilience researchers were eager to understand and investigate the origins and roles of reorganization and transformation processes of adaptive systems. This refers to evolutionary processes of economic, ecological and social systems that differ in speed and occurrence, and may interact on scales that reach from global to local. This is why Holling and his colleagues introduced a new concept: panarchy (Bunnell 2002; Gunderson and Holling 2002; Holling and Gunderson 2002; Holling, Gunderson et al. 2002; Yorque, Walker et al. 2002).

The term panarchy was created as an antithesis to the word hierarchy, whereby hierarchy here refers to a set of holy rules. Holling and his colleagues found that the concept of hierarchy sounded too rigid and "top-down", so they introduced the word panarchy. "Pan" refers to the Greek word for"God of Nature" and "archy" for rules. Panarchy is being displayed as in Figure 26, which can be seen as an extension of the adaptive cycle theory. Alpha and omega phases, like in Figure 24, refer to reorganization and destruction phases as before. "K" and "r" are the usual growth and selection processes[32] in ecologic theory and correspond to the conservation and growth phase (K) as well as to the exploitation and pioneering phase (r) in Figure 24 and Figure 25. The scales are interconnected by multiple ties, the two most important of which are referred to here as "revolt" and "remember".

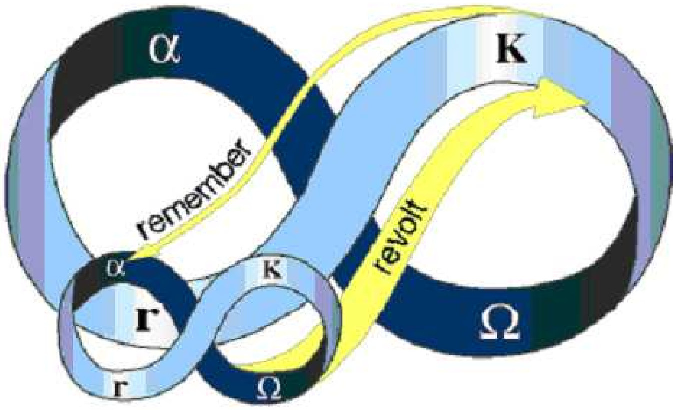

Figure 26: Panarchy: a set of adaptive cycles in which one is nested in the other, and in which interactions take place across various levels
Source: http://www.resalliance.org/index.php/panarchy

The fast levels invent experiment and test; the slower levels stabilize, and conserve accumulated memory of past successful, surviving experiments. Slower and larger levels set the conditions within which faster and slower ones function, e.g. a forest provides its inhabitants with a certain microclimate (Bunnell 2002). However, the periodic, but transient phases of destruction (e.g. in the aftermath of a forest fire or hurricane) facilitate the integration of new, innovative, and exotic elements into the system, which may lead to substantial changes. The adaptive cycle constantly includes mutations and reorganizations within each hierarchical layer, especially in the alpha-phase. In order not to risk the integrity of the overall system, experiments are at first partially isolated, and confined to their layer.

[32] K-selection: occurs in stable ecosystems; longevity of organisms, few offspring; large bodies (e.g. whales, elephants, humans). R-selection: unstable ecosystems; short lifespan, many offspring, large dissemination, small bodies (e.g. most insects, rodents, bacteria).

In many ways, panarchy may thus be regarded as biological evolution. It is a creative as well as conservative process – interactions between cycles combine learning processes with continuity. This results in an unambiguous definition of sustainable development: sustainability is the ability to create, test and maintain adaptive capacity; development is the process in which possibilities are created, tested, and maintained (Bunnell 2002)

3.4.1.6 Adaptability and Transformability

Recommendations concerning the policy resulting from this content are also decisive for economic resilience (or socio-economic resilience). It would be wrong to think it is sufficient to simply increase a system's resilience. As we already mentioned, a change of system (i.e. a shift to a different basin) may also lead to subjective improvement for participants. "Adaptability" and "transformability" are thus key concepts in resilience research of SES. Adaptability here refers to people's ability to deal with changes by observing, learning and adapting their influence on the environment.

Resilience analysis is about generating systemic knowledge which increases adaptability. The knowledge includes: in which basin the system is located (Figure 23); the place it is located at in this basin (compared to the thresholds); how it can be controlled (to avoid the move to a less desirable basin, or to actively move to a better one); how stability landscape can be changed in a way to facilitate (or complicate) control, and how a system can be transformed into another system (transformability) if this is the only possible and sensible option (www.resalliance.org) (Berkes and Folke 1998; Walker, Holling et al. 2004).

3.4.1.7 Adaptive Resource Management

The overall term for this approach is "adaptive resource management" (Holling 1978; Walters 1986). It is referred to as an integrative, multidisciplinary approach. Resilience researchers and others regard this approach as the necessary basis for sustainable development. "Adaptive" here refers to accepting that human interference constantly leads to changes of resources; that surprises are inevitable; and that uncertainties add to an ever developing situation. Management concerning this area thus presupposes that political actions do not only have to fulfil static social aims but have to be flexible enough to be constantly modified.

When referring to adaptive management, it is assumed that the system knows its own needs best. This is why stakeholders contribute to the process with their local knowledge, e.g. concerning institutional learning (Gunderson 1999). What is more, for adaptive management an adaptive leadership has to be established (Walker 2004). This leadership primarily relies on the self-organisation of social agents. To sum up, adaptive resource management may be referred to as a process that promotes adaptability and transformability in an SES.

Walker et al (2002) name four possible steps in such an adaptive management process: (1) participative processes with representatives of stakeholder groups to determine the most important attributes of the system; (2) determine, in which direction the stakeholders would like to influence the system. (3) Using this information to conduct a more specific, quantitative analysis and determine where resilience is; and (4) carrying out an integrated evaluation of management and policy conclusions in question, while involving scientists and stakeholders. The science-policy dialogue with stakeholders and the publication of policy papers[33], which will be elaborated later on, were partially based on these recommendations.

3.4.2 Vulnerability

The concept of vulnerability also stems from the field of disaster research. According to the latest scientific findings, resilience is regarded as a sub-topic of vulnerability. See
Figure 27a and 27b.

To decrease vulnerability, it is advised to enforce adaptive management, and adapt the five types of capital that are necessary to do so (see Figure 28). It is important to restrict oneself not only to one or a few of these capitals. Consider, for example, the vulnerability of a community hit by flooding. There are several strategies to cope with vulnerability. This community may build a reservoir a bit further upstream (capital produced by humans); it may invest in the education of fellow citizens and develop better early warning systems (human capital); it may create social capital, like NGO's that help victims of flooding, or promote general solidarity; create financial assets (funds for victims of disasters), and take out insurances (financial capital) and/or plant trees upstream to prevent land- and mudslides (natural capital).

[33] http://www.wachstumimwandel.at/engagement/policy-papers/

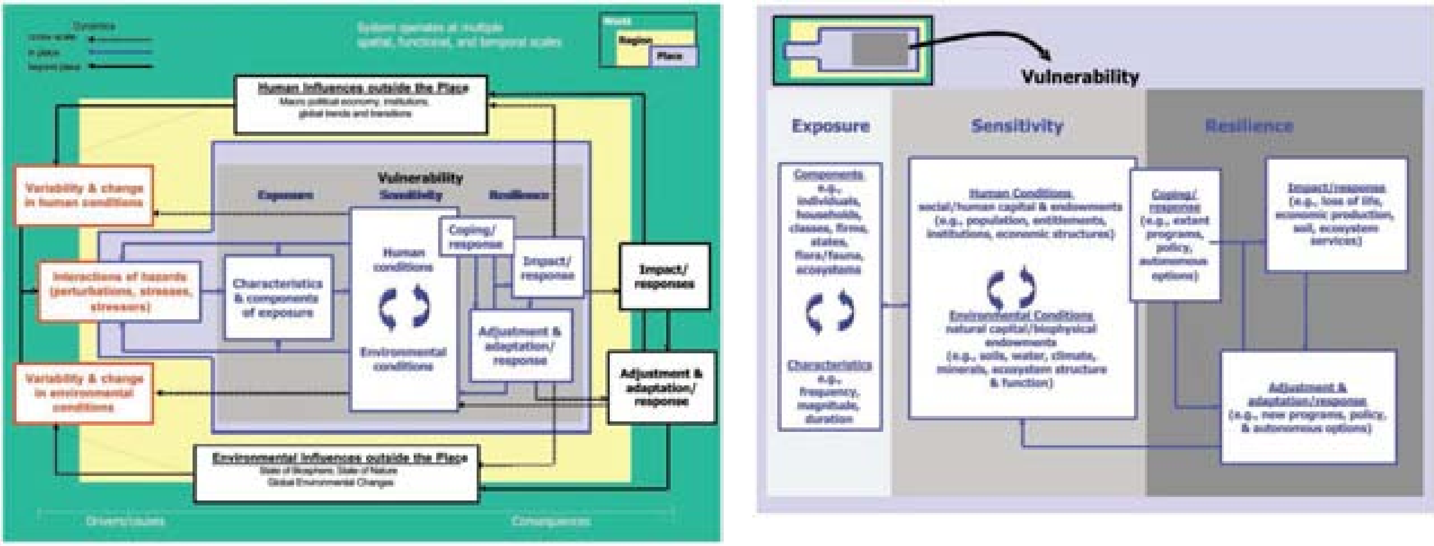

Figure 27a and 27b: resilience nested into the concept of vulnerability
Source: Turner et al. (2003)

3.4.3 Adaptive Resource Management: Stakeholder discussions concerning macroeconomic resilience and economic growth

3.4.3.1 Background: Initiative "Wachstum im Wandel" ("Growth in Transition")

The Austrian initiative Wachstum im Wandel (WiW) (Growth in Transition), which is organised by SERI (Sustainable Europe Research Institute), is motivated by the fact that promoting economic growth still seems to be the politically preferred answer to pressing problems such as unemployment, poverty and pollution[34] (compare e.g. World Bank 2008). In fact, more and more experts of various disciplines agree that maintaining the currentpath of economic growth is neither possible, nor desirable.

It is to be expected that economic growth cannot be boosted within the next few years, not neither globally nor within Austria. Sources of permanent growth decline constantly, resources become scarcer and more expensive (resource peaks), especially energy raw materials (peak oil, etc.) (Meadows, Meadows et al. 1992; Stern and Cleveland 2003; Nel and van Zyl 2010; Hall and Klitgaard 2011; Murphy and Hall 2011), the income generating population decreases in many countries (larger financial expenses for pensions), the government debts are rising and become more expensive to servcie, private and public possibilities to consume and invest are limited, and similar symptoms occur in most countries that are major importers of Austria's products.

[34] Keynesianist critics of the late EU austerity programmes find that the declared belief in a politics of economic growth is only rhetorical and that these programmes lead to recession.

However, there is not only a negative side to this development. Sustainable researchers more and more agree that previous patterns of economic growth are not compatible with sustainable development (Odum and Odum 2001; Victor 2008; Jackson 2009; Kallis, Kerschner et al. 2012). They neither created requirements for full employment, fair distribution, and better well-being (Adger 2006), nor reduced the levels of resource use (Dittrich, Giljum et al. 2012) and the pollution this creates(Millenium Ecosystem Assessment 2005; Rockström, Steffen et al. 2009). Some even name the fixation on economic growth as the root cause for the current multidimensional crisis of democracy, social fabric, and the environment (Speth 2009; Speth 2012).

Already today we increasingly notice that not everything that grew in the past, or grows today, indeed leads to more prosperity, quality of life, or makes a good life possible. The growth path of industrialised countries such as Austria was and is connected to high ecological and social costs that should no longer be ignored. These conditions ask for a new definition of what is being referred to as welfare. Sustainable growth demands the design of a new model of welfare, one that is no longer dependent on high growth rates. The concept of economic resilience offers a suitable framework to do so.

3.4.3.2 Policy-Science-Stakeholder Dialogue

"Wachstum im Wandel" initiated a policy-science-stakeholder dialogue that aimed at creating a policy paper concerning resilience and economic growth within the before mentioned context. This dialogue's central topic is how the Austrian economic system can, in times of global change (e.g. scarce resources, climate change, demographic change, current unequal global distribution, etc.), be turned into a sustainable one, and which general issues for society as a whole have to be tackled within the next decade. The long term vision is a resilient economy in terms of adaptability and transformability. For more than a year, the initiative "Wachstum im Wandel" elaborated the content of certain topics that are relevant for economic growth in so-called policy-science-stakeholder dialogues. Addressing questions with the heading "Growth and…", more than 100 experts and stakeholders worked on the topics of "work", "government spending", "quality of life", "resilience", "leadership", "energy", "ecosystem services", and "money". Further topics are still to be discussed (e.g. the question of distribution, pension policies, developing countries, innovation and technology, etc.) to sufficiently understand the interaction between a different concept of growth and important political agendas within the next few years. The knowledge thus generated will be summarised in “policy papers”, which include detailed advice on measures that can be taken. [35]

The paper “Resilienz in einer weniger, nicht oder anders wachsenden globalen und österreichischen Wirtschaft“ (“Resilience in a less, not, or differently growing global and Austrian economy“) (Kerschner 2012), which includes findings of the stakeholder dialogue which is part of it (list of participants included in the appendix), is part of this process. In the following, only that part of the discussions is reproduced, which explicitly deals with resilience and vulnerability.

3.4.3.3 Problems when referring to the concept of resilience

The previously mentioned stakeholder dialogue quickly showed that an interpretation of the concept “resilience” is not unambiguous. On the one hand, people are tempted to view resilience in an exclusively positive sense, which is why the increase of a system’s resilience is commonly regarded as the best solution. Especially with SES and in connection with sustainable development this proves to be a fatal error, because it is precisely a change of an existing (very often too resilient, too sluggish) system which is intended. This tendency is further increased by the fact that resilience is close to disaster research. This means, resilience is often understood only in its engineering definition; in the static sense (averting crises and disaster), as well as in the dynamic (returning to the original state after a crisis or disaster). The need to control and to be in command of the system (e.g. because of fear for changes) are predominant.

Ecologists, however, increasingly emphasise that changes are part of a system and the main aim is to support its adaptability, or to influence its “fitness landscape”. One of the participants of the stakeholder dialogue even described our society as having a “pathological attitude” to changes. One of the most important reasons why our system is overly optimised, in poor health and deprived of the ability to develop is that people primarily seek to avert crises. Instead, adaptive co-management should be implemented. The ultimate problem in connection with this is further that the type of benchmarking systems and scales that are being selected to measure development, are not being publicly discussed. This would be most important for the measurement of growth. In ecological literature authors agree that a system can only develop when it is able to overshoot as well as undershoot, i.e. development is marked by phases of growth as well as recession.

[35] The papers will be posted here shortly: http://www.wachstumimwandel.at/engagement/policy-papers/

This argument has been confirmed by others, and the essential question asked is: do we really want to make our system more resilient, when keeping the previously mentioned challenges in mind, or are we already looking for a radical change of system? In line with these thoughts, the graphics by Holling and his colleagues are not useful for SES, as the change to another basin already gives the impression that this is negative. Fath (2012) provides a more complex model that not only includes basins and valleys (great stability – low fitness), but also hills (less stability – high fitness). When applying this concept to socio-ecological and economic systems, we can draw the conclusion that a collapse of our economic systems may indeed lead to an improvement of the current situation. However, this leads to the urgent subject of what will happen during the period of change, or in the valley? Will the consequences lead to socio-economic traumata, e.g. wars, famines, etc.? This is precisely the reason why Peter Victor argues for a transition "by design not disaster": (Victor 2008).

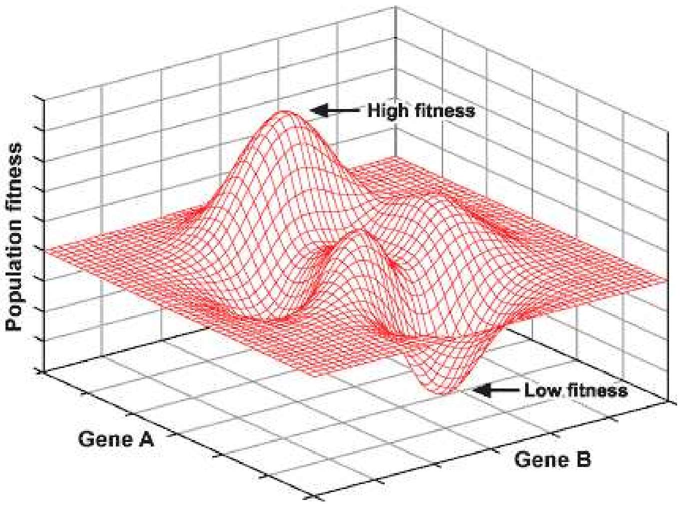

Figure 28: fitness landscapes
Source: Fath 2012

3.4.3.4 Is vulnerability therefore not a better concept than resilience?

Considering the previously mentioned issues concerning the concept of resilience, the stakeholder group came up with the question if "vulnerability" would not have been the better topic for the dialogue. Most issues that had been discussed were rather related to sub-topics of vulnerability: "exposure" and "sensitivity". The group came to the conclusion that vulnerability would be the better and more inclusive concept in this context. However, the counterargument that vulnerability is negatively connoted and thus unsuitable for political messages was also supported. It would, for instance, sound somewhat gloomy if someone said that Austria was vulnerable to bottlenecks of fossil energy. This is why politicians only talk of and demand energy self-sufficiency, as this sounds more powerful and positive. On the other hand, the sustainability discourse is now also increasingly departing from the dogma of "we should only tell positive stories”. A constructive use of both concepts seems imaginable to all participants.

3.4.4 Acknowledgements

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3.4.5 Appendix: Participants of the stakeholder dialogue

The following experts participated in two workshops on 25th April and 4th July 2012 where they contributed to the policy paper “Resilienz in einer weniger, nicht oder anders wachsenden globalen und österreichischen Wirtschaft“ (“Resilience in a less, not or differently growing global and Austrian economy“):

Mag. Thomas Reininger (OeNB), Univ.Prof.in Maga.Dr.in Sigrid Stagl (WU Wien), Ph.D. Jill Jäger (SERI), DI Gerhard Stimmeder (BMLFUW), Mag.a Dr.in Helene Schuberth (OeNB), Mag. Sven Hergovich (AK Wien), Dr. Harald Katzmair (FAS.research), DI. Nikolaus Morawitz (Landwirtschaftskammer Öst.), Mag.a Karin Steigenberger (WKÖ), Univ. Prof. Dr. Axel Schopf (BOKU), Dr. Robert Stöger (BKA), Univ. Prof. Dr. Brand Ulrich (UNI Wien), Mag.a Christina Bucko (ÖSFO), Brigadier Mag. Dr. Feichtinger Walter (Landesverteidigungsakademie), Mag.a Schmitzer Eva-Maria (BMWF), DI.Dr. Schriefl Ernst (Energieautark GmbH), Vera Ulmer (Bank Austria), Univ. Prof. Dr. Weber Leopold (BMWFJ)

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PART 2 [Paper I & Paper II]

Vulnerability and potential Impacts of Peak Oil

1 Introduction – Part 2

1.1 Peak-Oil: Vulnerability and Impact Analysis

In this part of my Thesis I am building on evidences regarding the occurrence of Peak-Oil within the short to medium term future and the energy systems theoretical reasoning for this to be a traumatic event for world economies. Systems theory in general, but most explicitly the resilience and vulnerability literature, stresses the need for adaptive resource management. Hence in this chapter I am offering a first step towards a systemic analysis of the potential local and national impacts and vulnerabilities. In order to design policy measures for adaptions, we need to know the properties of our system well.

Very little is known so far about the impacts of energy shocks on modern economies, which is a difficult problem for modelling. Kerschner, Bermejo et al. (2010) however argued that best suited for such analysis were sectorially disaggregated economic models, like input output analysis. In the following chapters I am looking into the details of this method, for investigating its suitability for measuring potential economic impacts and vulnerabilities with regards to Peak-Oil. A philosophical justification for the use of IO analysis and an overview of its history can be found in Chapter 1.2. The basic IO table is described in the following Chapter, followed by an outline of the traditional Leontief model.

Nevertheless, it will be argued in that the traditional demand driven Leontief model is not suitable for analysing resource constraints, as it assumes unlimited supply of factor inputs. Therefore I look for alternative models for analysing both the quantity (Chapter 1.3) as well as the price dimension of Peak-Oil (Chapter 1.4). Unfortunately the supply driven model (Chapter 1.3.1), as to be discarded for its implausible assumptions. After the conclusion that a mixed or supply-constrained model would be appropriate for analysing the quantity dimension of Peak Oil, the method is applied to IO tables of the UK, Japan and Chile in Chapter 1.3.3 (more country results can be found in the Appendix of that Chapter). The impact of a ten percent reduction of output in the "crude oil and natural gas extraction" and "petroleum refining" sectors upon the output of the rest of the economy and upon their own final demands are measured. In Chapter 1.4 I provide the methodological background for the Leontief Price Model and provide the results of some first applications.

Chapter 1.6 reproduces a case study for measuring the vulnerability of the Basque economy towards Peak-Oil (Arto-Oliazola and Kerschner 2009). This study by Iñaki Arto-Oliazola and myself was one of the first detailed regional vulnerability studies regarding Peak-Oil. It uses a conglomerate of innovative indicators. The most important of them were derived by using a Multiregional IO Model. We measure distance travelled of Basque imports and exports and the energy intensity of the Basque industry, among several other indicators.

Chapter 2 and Chapter 3 present Paper I (Kerschner and Hubacek 2009) and Paper II (Kerschner, Prell et al. submitted), which have been already or are going to be published soon. Paper 2 is one of the highlights of this Thesis.

1.2 Input-Output Analysis: Suitable for Peak-Oil impact / vulnerability research?

1.2.1 Historical background of Input-Output Analysis and justification

Standard input-output analysis was developed by Nobel price laureate Wassily Leontief (1936; 1941). However Leontief did not invent input-output (IO) tables, on which the analysis is based. He merely formalized a concept called "Tableau Economique", put forward already in 1758 by the French physiocrat Francois Quesnay (Miller and Blair 1985). In his table Quesnay tried to describe the economic interdependencies which he had been observing: A land owner would spend half of the rent he received on agricultural products and half on artisan products. The farmers on the other hand would pay rent and buy industrial goods, just as artisans would by food and raw materials.

These observations still resemble what is being visualised in Leontief's input-output table today. In its most basic form *inter-industry*[36] *analysis*, as it is also called, is a framework, consisting of a system of linear equations. Every one of them describes the distribution of one particular industry's product within the economy. As such they are in fact an approximation of the general equilibrium model developed by another French economist, Leon Walras (1954 [1874] ; cited in: Miller and Blair 1985). Walras used the principles of Newtonian mechanics to develop a theory of general equilibrium in economics and in doing so used similar production coefficients as can be found in Leontief's IO analysis. Leontief presented the theoretical framework together with two US tables in his article '*Quantitative input and output relations in the economic system of the United States*' (Leontief 1936). Later he also

[36] The words industry and sector are used interchangeably in this text and in the IO literature in general.

developed the first IO models which were based on IO tables. In his book '*The structure of American economy,* 1919-1929' Leontief (1941) introduced the assumptions that evolved into the now well-known IO model.

Today IO Tables are being generated on a regular basis for all OECD countries and the standardization of the framework has been promoted by the United Nations (Miller & Blair 1985). The subsequent development of IO analysis, after the pioneering work of Leontief, has been within its two major areas of application: accounting and modelling. Articles on IO modelling used to appear on a regular basis in most prestigious economic journals up to the late 1970's. Since then the method seems to have fallen into dismay with mainstream economists, despite the fact that IO models are still widely applied (Los 2001). More recently they have become a popular tool for ecological-economic analysis i.e.: for studying nature-economy relationships. This has become possible as the IO framework was extended to deal with the analysis of energy consumption and environmental pollution.[37] Nowadays environment and life cycle analyses together with regional economics are the main uses of IO modelling.

The reasons for this popularity are various. Firstly, IO models allow fairly detailed descriptions of an economy due to the high levels of disaggregation which can be found in IO tables. Secondly it is useful for analysing economic changes, as it allows to quantify not only the direct, but also the indirect effects of certain economic phenomena (e.g.: a sudden shift in consumption patterns). Thirdly the framework is based on straightforward assumptions and fairly simple algebra (Oosterhaven 1988), not requiring an excessive level of professional specialisation, which makes it easy to understand, apply and interpret (Hoekstra 2005). Nevertheless it is also argued that the very same fact is one of the biggest enemies of the IO model, "… as these properties have induced too many applications and academic exercises that disregard the economic implications of what is actually done" (Oosterhaven 1989, p. 465). Oosterhaven (1989) particularly refers to the treatment of supply in the framework, which will be discussed below. Finally all the favourable attributes mentioned above enable the researcher to avoid the *fallacy of misplaced concreteness*, when using the tool.

[37] These are not the only areas the IO framework has been extended to, others are employment associated with industrial production and interregional flows of products (Miller and Blair 1985)

This fallacy was first described by Whitehead (1929; cited in: Daly and Cobb 1989), and is otherwise inherent in mainstream economic theory (Georgescu-Roegen 1971). In general terms this " (…) is the fallacy involved when thinkers forget the degree of abstraction involved in thought and draw unwarranted conclusions about concrete actuality" (Daly and Cobb 1989, p. 36). The level of abstraction from reality is clearly visible due to the simplicity of the IO model and its fundamental assumptions. Thus it allows regular "recurrence to the concrete in search of inspiration" (Whitehead 1929).

More specifically IO analysis is well suited to make contributions to Aristotle's four causes: *material, efficient, formal* and *final*. Using the analogy of building a house as in Daly and Cobb (1989), the material cause is the lumber and bricks; the efficient cause is the carpenter and the tools he uses to modify the materials; the formal cause is the plan the carpenter follows and the final cause is the purpose of the house e.g.: provision of shelter, home, etc. The IO framework uses real world figures in monetary or physical (matter) terms (or both); can incorporate different actors of change e.g.: final demand changes due to government spending, policies etc. (efficient); unveils the structural relationships within an economy (formal) and allows the interpretation of changes in terms of how well they coincide with a predefined purpose or goal e.g.: sustainability (final).

Leontief believed in IO analysis, because he was convinced it could "*reduce the steadily widening gap between factual observation and deductive theoretical reasoning that threatens to compromise the integrity of economics as an empirical science*" (Leontief 1989, p. 3). Earlier he had expressed his concern about the growing abstraction and mathematization in the Economics discipline in an open letter to *Science*: "*Page after page of professional economic journals are filled with mathematical formulas leading the reader from sets of more or less plausible but entirely arbitrary assumptions to precisely stated but irrelevant theoretical conclusions… (E)conometricians fit algebraic functions of all possible shapes to essentially the same sets of data without being able to advance, in any perceptible way, a systematic understanding of the structure and operations of a real economic system*" (Leontief 1982, pp. 104&107)

1.2.2 The basic Input-Output table

The IO transactions table consists of **rows**, describing how a producer's output is distributed among the other sectors and final demand within an economy, and of **columns** describing the composition of inputs required by a particular sector to produce its output i.e. its production function. In other words columns show "Who receives from whom?" and rows "Who gives to whom?" in an economy. Mathematically this can be depicted as a set of *n* linear equations with *n* unknowns, which allows the representation of the IO system in matrix format. Table (3) below provides an illustration of a simplified IO-table for a three-sector economy. Total Output of agriculture [x_1][38] for example is given by the sum of entries in **row** 1. It is made up of intermediate deliveries to agriculture itself [z_{11}], to manufacturing [z_{12}] and services [z_{13}] plus final demand [y_1], consisting of household (y_{11}) , investment (y_{12}), government (y_{13}) and export demands (y_{14}) [compare equations (1) and (2)]. The total output of the whole economy in matrix terms can therefore be represented as in equation (3). Further down, the sum of the Labour-, Other- and Import-row equal the total output of (wo)man-hours, other human services/resources [e.g.: government services (taxes), capital costs (interests), land (rent), entrepreneurship (profits), etc.] and imports generated within the economy respectively.

(1) $x_1 = z_{11}+z_{12}+z_{13}+y_{11}+y_{12}+y_{13}+y_{14}$
$x_2 = z_{21}+z_{22}+z_{33}+y_{21}+y_{22}+y_{23}+y_{24}$
$x_3 = z_{31}+z_{32}+z_{33}+y_{31}+y_{32}+y_{33}+y_{34}$ or in general terms

(2) $x_j = \sum_{i}^{n=1} z_{ij} + w_j$ or in matrix annotation

(3) $\mathbf{x} = \mathbf{Zi} + \mathbf{y}$ [**i**.........summation vector of 1nes in appropriate size]

(4) $\mathbf{y} = \mathbf{Yi}$

[38] For clarity, matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters, and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime (e.g. x'). A diagonal matrix with the elements of vector x on its main diagonal and all other entries equal to zero are indicated by a circumflex (e.g.: $\hat{\mathbf{x}}$) or by putting the term in between circumflex brackets (e.g.: $\langle \mathbf{Wi} \rangle$). Denominators of matrix dimensions and vector lengths (i, j, n, m, etc.) are also printed in italics.

	to (j) / from (i)	Processing sectors			Final Demand (Y) (I x R)				Total Output (x) (j)
		Agri-culture	Manu-facturing	Services	House-…	Invest-…	Govern-ment (G)	Exports (E)	
Processing Sectors (Z) (I x J)	Agriculture	z_{11}	z_{12}	z_{13}	y_{11}	y_{12}	y_{13}	y_{14}	x_1
	Manufacturing	z_{21}	z_{22}	z_{23}	y_{21}	y_{22}	y_{23}	y_{24}	x_2
	Services	z_{31}	z_{32}	z_{33}	y_{31}	y_{32}	y_{33}	y_{34}	x_3
Payments Sector (W) (S x J)	Labour (l)	w_{11}	w_{12}	w_{13}	l_H	l_I	l_G	l_E	l
	Other[39] (n)	w_{21}	w_{22}	w_{23}	n_H	n_I	n_G	n_E	n
	Imports (m)	w_{31}	w_{32}	w_{33}	m_H	m_I	m_G	m_E	m
Total Outlays (x') (i)		x_1	x_2	x_3	h	i	g	e	X

Table (3): The basic Input-Output Table

The **column** sums of the Table (3) on the other hand provide the production function for each sector i.e. the inputs it needs from other sectors (and itself) plus **W**, which includes value added [l and n] and imports [m]. (**W** is a matrix of s primary inputs (value added) times j sectors; its elements thus being w_{sj}.) Column sums therefore illustrate for example how much food, machinery, fertilisers, services, man power, land, etc. is necessary to produce the total agricultural output [see Eqs. (5), (6), (8) and (7)]. On the right hand side (quadrant 2 and (4) of Table (3) the column sum represents the final demand for the products of each processing and payment sector by households [H], investment [I], government [G] and exports [E]. Value X in the right hand corner of Table (3) can be calculated in two ways, either by making the bottom row (9) or the right hand side column sum (10). Equating the two expressions and cancelling out x_1, x_2 and x_3, one obtains (11), which shows gross national income (GNI) on the left and gross national product (GNP) on the right.

(5) $x_1 = z_{11} + z_{21} + z_{31} + w_{21} + w_{21} + w_{31}$
$x_2 = z_{12} + z_{22} + z_{32} + w_{12} + w_{22} + w_{32}$
$x_3 = z_{13} + z_{23} + z_{33} + w_{23} + w_{23} + w_{33}$… or in general terms

(6) $x_j = \sum_{j}^{n=1} z_{ij} + w_j$ w_j ….. Element of vector **w**, given by:

(7) $\mathbf{x' = i'Z + w}$ [**i'**…….transposed summation vector **i**]

(8) $\mathbf{w = i'W}$

(9) $x = x_1+x_2+x_3+l+n+m$

(10) $x = x_1+x_2+x_3+h+i+g+e$

(11) $l+n+m=h+i+g+e$ ....[GNI=GNP]

z_{23}...........................	Manufactured goods provided to the service sector e.g.: computers
z_{33}...........................	Services provided from service sector to itself e.g.: computer repair
w_{12}...........................	Payment to workers in the manufacturing sector e.g.: factory
w_{23}...........................	Payment for Services provided by Government to the service sector e.g.: roads, paid through taxes
l_G...........................	Payment to Government workers
l_H...........................	Household payments for labour services e.g.: domestic help, etc.
n_H...........................	E.g.: interest payments, taxes, rent paid by households
m_G...........................	Government purchases of imported items
m_E...........................	Imported goods which are re-exported

Table (4): Examples for the meaning of some selected variables from Table (3) above

As already mentioned IO Tables are nowadays produced for all OECD countries and many other countries in the world. They provide an excellent, simplified, easily comprehendible representation of the economic structure of a particular country.

1.2.3 IO Modelling: The traditional Leontief IO Model (The input or demand-side approach)

It is worth drawing a distinction between an IO table and IO models here. The former could be described as an accounting tool which is specifically geared for its application in IO modelling. Therefore it has to incorporate the assumptions of IO models. IO models on the other hand are, just like any models, "*interpretative descriptions of a phenomenon that facilitates access to that phenomenon*[40]. (…) *This access can be perceptual as well as intellectual* (Bailer-Jones 2002, p. 108f)." This facilitation of access usually goes hand in hand with focusing on specific aspects of phenomena only i.e. abstractions from reality. Other aspects of the phenomena are more or less deliberately disregarded (Bailer-Jones 2002).

In the traditional Leontief model, the sectoral outputs are derived from exogenously specified final demands. The model is also being referred to as "demand-driven" because it is the final demand vector **y** (or final demand matrix **Y**) that drives the model entirely. It determines total outputs (**x**), intermediate inputs (**Z**) and primary inputs (**W**) via a set of fixed coefficients. This approach examines how much is needed of the output from preceding, vertical stages or of the primary inputs, either for final use or for a unit of output of some industry (Augustinovics 1970). The first step in using the information given in IO tables is to calculate

[40] Phenomenon in this context covers objects as well as processes (Bailer-Jones, 2002).

the individual technical input coefficients, also called purchase coefficients, i.e. the direct backward linkages[41]. The most important abstraction from reality in IO modelling is the assumption of these coefficients to be constant i.e.: the inputs acquired by sector *j* from sector *i* depend entirely on the total output of sector *j*. Technical coefficients [a_{ij}] are calculated as shown in (12). This ratio indicates how many €'s worth of inputs from sector *i* are necessary per one € worth of total output from sector *j*.

(12) $$a_{ij} = \frac{z_{ij}}{x_j}$$ or in matrix form

(13) $$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$$ [$\hat{\mathbf{x}}$ ….. diagonalised vector **x**] or

(14) $$\mathbf{A} = \begin{bmatrix} \frac{z_{11}}{x_1} & \frac{z_{12}}{x_2} & \frac{z_{13}}{x_3} \\ \frac{z_{21}}{x_1} & \frac{z_{22}}{x_2} & \frac{z_{23}}{x_3} \\ \frac{z_{31}}{x_1} & \frac{z_{32}}{x_2} & \frac{z_{33}}{x_3} \end{bmatrix}$$ if applied to Table (3)

This assumed fixed relationship between a sector's output and its input, implies also the assumption of constant returns to scale and a fixed proportion of inputs i.e. a fixed production function. This means that not only a_{ij} is assumed fixed, but also the ratio between total output of a sector and its primary inputs (i.e. labour, capital,..). This ratio for an economy with *s* primary inputs is given by the coefficient c_{si}, which is formalized in Eq. (15). Note that the sum of technical input coefficients (**A**) and primary input coefficients (**C**) have to amount to unity (**i'**), because of Eq. (4) [compare Eq. (17)]. Note also that this fixed ratio only refers to monetary inputs included in value added and not any physical ones which are not accounted for in value added e.g.: natural resources. Theoretically fixed input coefficients can be justified on the basis of the Walras-Leontief production function, where firms are assumed to operate a cost-minimizing strategy [Eq. (18)]. In reality of course there are always a variety of alternative input combinations.

(15) $$c_{sj} = \frac{w_{sj}}{x_j}$$ or in matrix annotation

[41] The term backward linkages is used to describe the level of interconnection between a particular sector and the sectors from which it purchases inputs. The elements of the A matrix only capture the direct backward linkages, while the elements of the Leontief inverse, described below, take account of both, direct and indirect backward linkages (Miller and Blair 1985).

(16) $\mathbf{C} = \mathbf{W}\hat{\mathbf{x}}^{-1}$

(17) $\mathbf{i'A} + \mathbf{i'C} = \mathbf{i'}$

(18) $$x_j = \text{Min}\left(\frac{z_{ij}}{a_{ij}} \text{ for all } i,\ \frac{w_{sj}}{c_{sj}} \text{ for all } s\right)$$

Usually the question to be answered in demand-side IO modelling, is the following: If final demand from one or more of the exogenous sectors (e.g.: households, government, etc.) is expected to increase or decrease in the future, how would this affect the total output [**x**] necessary to satisfy this new demand and its ripple effects throughout the economy? In order to get **x**, Eq. (13) is firstly transformed into Eq. (19). Replacing **Z** in (4) then gives Eq. (20). Bringing all the **x** onto one side equals (21), which can then be transformed into (22) and finally **X** can be found when pre-multiplying **y** with the so called *Leontief Inverse* in Eq. (23). This inverse, $(\mathbf{I}-\mathbf{A})^{-1}$, provides a new matrix which shall be denoted as **Ω** and its elements as α_{ij}. A value of say 0.5 for α_{23}, would indicate that in order to satisfy 1 € worth of increase in the service sector's (j=3) final demand (Δy_3=1), requires 0.5 € worth of increased output in the manufacturing sector (i=2) i.e. $\Delta x_2 = 0.5$

(19) $\mathbf{A}\hat{\mathbf{x}} = \mathbf{Z}$

(20) $\mathbf{x} = \mathbf{A}\hat{\mathbf{x}}\mathbf{i} + \mathbf{y}$

(21) $\mathbf{x} - \mathbf{A}\mathbf{x} = \mathbf{y}$ [Note that $\hat{\mathbf{x}}\mathbf{i} = \mathbf{x}$]

(22) $(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y}$

(23) $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$ denoting the elements of $(\mathbf{I}-\mathbf{A})^{-1}$ as α_{ij} this can be resolved as:

$$x_1 = \alpha_{11}y_1 + \alpha_{12}y_2 + \ldots + \alpha_{1j}y_j + \ldots + \alpha_{1n}y_n$$
$$\vdots$$
(24) $$x_i = \alpha_{i1}y_1 + \alpha_{i2}y_2 + \ldots + \alpha_{ij}y_j + \ldots + \alpha_{in}y_n$$
$$\vdots$$
$$x_n = \alpha_{n1}y_1 + \alpha_{n2}y_2 + \ldots + \alpha_{nj}y_j + \ldots + \alpha_{nn}y_n$$

Summary of Assumptions and Limitations of the Leontief IO Model
Strictly demand-driven
Constant input / production coefficients[42]
Constant price ratios between inputs (if based on monetary data)
Constant returns to scale
Absence of substitution possibilities between inputs
Absence of supply constraints
Price elasticities of zero
Forward production effects of zero i.e.: only backward linkages are accounted for

1.3 The Quantity dimension of Peak-Oil within IO Analysis

1.3.1 The output or supply-side approach

The standard I-O model as already mentioned above is driven by exogenous demand changes. In other words $\mathbf{y}^{\text{new}}$ is exgenously given and $\mathbf{x}^{\text{new}}$ can be calculated by multiplying it with the Leontief Inverse as in Eq. (25). Beneath this procedure lies the assumption that all input requirements for the production of this new demand will automatically and instantaneously (i.e. within the given statistical year) be met. This is only justifiable given the existence of unused capacity and very elastic factor-supply curves (Giarratani 1976).

$$\text{(25)} \qquad \mathbf{x}^{\text{new}} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{y}^{\text{new}}$$

On the basis of this argumentation Ghosh (1958) developed an allocation model as an extension of the traditional Leontief system. This involves rotating the previous vertical (column) view of the standard IO model to a horizontal (row) view if looking at Table (3). Whereas the flows of products and values are described in terms of 'where they come from' in the demand-side approach, the supply-sided approach asks 'where they go to' (Augustinovics 1970). Primary supply vector **w** (or matrix **W**) is now the exogenous driving force, determining **x**, **Z** and **Y**. Instead of assuming fixed *input* coefficients like in the standard model, the Gosh-model[43], as it is also referred to, assumes fixed *output* coefficients,

[42] It is worth mentioning her that there is also a dynamic IO model (e.g.: Duchin and Szyld 1985) and the "case study approach" used by Duchin and Lange (1992), Idenburg 1993 and others, both of which allow to address this assumption.

[43] Supply-side, supply-driven, output and Gosh model are used indiscriminately in this text.

also known as sales or allocation coefficients i.e. forward linkages[44]. Thus the result of, say, a tripling of the output of the agricultural sector will be a tripling of the sales to all sectors that purchase agricultural products.

The supply-side allocation coefficient matrix **B** will then be calculated by dividing each *row* [*i*] of **Z** by the gross output of the sector associated with that *row*. In the standard model it was the *column* [*j*]of **Z** which was divided by the gross outlays (inputs) of the *column* associated with that sector. The corresponding equations are shown below [Eqs.(26)-(28)]. The letters b_{ij} and **B** have been chosen here to denominate the allocation coefficients and the allocation coefficient matrix respectively.[45] Ratio b_{ij} indicates how many €'s worth of output are generated in sector *j* if total outlays of sector *i* are increased by one €. The parallel to primary input coefficients c_{sj} and matrix **C**, are final demand coefficients d_{it}, for *t* final demand sectors and matrix **D** provided in Eq. (29) and Eq. (30) respectively. Note that because of Eq. (1-6), **B** and **D** have to amount to **i** [compare Eq. (31)]

(26) $$b_{ij} = \frac{z_{ij}}{x_i}$$ or in matrix annotation

(27) $$\mathbf{B} = (\hat{\mathbf{x}})^{-1}\mathbf{Z}$$ or if applied to Table 1

(28) $$\mathbf{B} = \begin{bmatrix} \frac{z_{11}}{x_1} & \frac{z_{12}}{x_1} & \frac{z_{13}}{x_1} \\ \frac{z_{21}}{x_2} & \frac{z_{22}}{x_2} & \frac{z_{23}}{x_2} \\ \frac{z_{31}}{x_3} & \frac{z_{32}}{x_3} & \frac{z_{33}}{x_3} \end{bmatrix}$$

(29) $$d_{it} = \frac{y_{it}}{x_i}$$ (y_{it}.....elements of final demand matrix **Y**)

(30) $$\mathbf{D} = (\hat{\mathbf{x}})^{-1}\mathbf{Y}$$

(31) $$\mathbf{Bi} + \mathbf{Di} = \mathbf{i}$$

As shown above total outputs [**x**] and totals outlays [**x'**] are by definition identical in an IO table. **x***'* is obtained as in Eq. (7) [i.e. **X***'* = **i'Z** + **w**]. Hence we can follow similar steps as above from Eq. (19) to (23) in order to arrive at the *output inverse*- the supply-side equivalent of the Leontief Inverse - which is pre-multiplied by **w** [Eqs. (32) – (36)]. The resulting

[44] The term forward linkages refers to the level of interconnection between a particular sector and those sectors to which it sells its output to. The elements of matrix **B** only reflect the direct forward linkages while the Ghosh Inverse discussed below captures both direct and indirect forward linkages (Miller and Blair 1985).

[45] Some writers use $\vec{\mathbf{A}}$ instead of **B** to indicate the row-focus of the supply-side model and $\mathbf{A}\downarrow$ instead of just **A** for the demand-side model (e.g. Augustinovics 1970).

elements q of **Q**, which is $(\mathbf{I}-\mathbf{B})^{-1}$ as in Eq. (36), can be interpreted as in the following example: If q_{13} equalled 0.12, then a reduction of 1€ worth of available primary input (e.g. labour due to a strike) to the agricultural sector, would cause 0.12€ worth of reduction in the output of the service sector. Augustinovics (1970) has shown that input and output approach can always be transformed into each other as shown in Eq. (38) and (39). This biproportional relationship can easily be arrived at by combining Eq. (27) and Eq. (13) above.

(32) $\hat{\mathbf{x}}\mathbf{B} = \mathbf{Z}$

(33) $\mathbf{x}' = \mathbf{i}'\hat{\mathbf{x}}\mathbf{B} + \mathbf{w}'$ [**x***'*..........**x** transposed i.e. as a row vector]

(34) $\mathbf{x}' - \mathbf{x}'\mathbf{B} = \mathbf{w}'$ [Note that $\mathbf{i}'\hat{\mathbf{x}} = \mathbf{x}'$]

(35) $\mathbf{x}'(\mathbf{I} - \mathbf{B}) = \mathbf{w}'$

(36) $\mathbf{x}' = \mathbf{w}'(\mathbf{I} - \mathbf{B})^{-1}$ which is the matrix representation of:

(37)
$$\begin{aligned} x_1 &= \mathbf{w}_1 q_{11} + \mathbf{w}_2 q_{21} + \ldots + \mathbf{w}_i q_{i1} + \ldots + \mathbf{w}_n q_{n1} \\ &\vdots \\ x_j &= \mathbf{w}_1 q_{1j} + \mathbf{w}_2 q_{2j} + \ldots + \mathbf{w}_i q_{ij} + \ldots + \mathbf{w}_n q_{nj} \\ &\vdots \\ x_n &= \mathbf{w}_1 q_{1n} + \mathbf{w}_2 q_{2n} + \ldots + \mathbf{w}_i q_{in} + \ldots + \mathbf{w}_n q_{nn} \end{aligned}$$

(38) $\mathbf{A} = \hat{\mathbf{x}}\mathbf{B}(\hat{\mathbf{x}})^{-1}$

(39) $\mathbf{B} = (\hat{\mathbf{x}})^{-1}\mathbf{A}\hat{\mathbf{x}}$

Gosh proposed the supply-driven IO model in 1958 as a tool to describe certain aspects of centrally planned economies, where a system of quotas or rationing is in place. In such an economy one would find "… unlimited demand for goods stimulated by development plans which is undiminished by higher prices" (Ghosh 1958). Price increases are not sufficient to reduce the expenditure function and the suppliers (or the government) may decide to introduce some arbitrary rationing scheme. Thus the system is no longer driven by consumer behaviour, but by institutionalised decision making. In these cases the rationing authorities would, at least in the short run, tend to maintain the historical levels of distribution of the scarce resource among competing sectors. The reason being, that "(…) *such relative shares are determined by a delicate balancing of different sectors' claims and counter-claims. This tendency considered from the problem of projection makes the allocation coefficients more stable in the short-run than production coefficients.*" (Ghosh 1958, p. 527).

Even in market economies, so Ghosh (1958), could such a situation arise if resources are scarce. The producer of a scarce good could feel the need to "…keep his market in his grip rather than sell only to the highest bidder" (Ghosh 1958, p. 527).Giarratani and Hydock (1978; cited in: Oosterhaven 1981) and Giarratani (1981; cited in: Oosterhaven 1988) agree and point out that in the case of sudden disruptions of supply and of excess demand in a market economy, firms might be tempted to allocate on the basis of historical sales patterns in order to maintain their existing markets. Moreover inertia in general could be a reason to justify the assumption of fixed output ratios in market economies. However if the good was an essential commodity such as petroleum, one would expect the government to step in and introduce a distribution system according to national needs. Such rationing systems have been in place in western economies during war times and later during the two oil shocks[46]. Finally, government services could be named as a product where the supplier, in both market and planned economies, could be expected to stabilize its output patterns in order to secure allocative equity among its clients (Oosterhaven 1988).

1.3.1.1 Fixed input coefficients

Theoretically the assumption of fixed output coefficients are somewhat more difficult to justify than the standard models' fixed input coefficients. As already mentioned the latter are based on behavioural assumptions originating from production theory i.e. cost minimization. The allocation model on the other hand is based on behaviour which we have little knowledge of (Giarratani 1980). Giarratani identified this as a potential weakness of the allocation model. Oosterhaven (1988) however disagrees and argues that simply because we know more about the Leontief model than the Ghoshian model, does not justify considering one better than the other.

Later on Hoover and Giarratani (1999 [1984]) stated that in practice it would actually not be feasible to create a supply driven model based on technical coefficients from a basic IO table. The reason for this claim is the fact that in western industrial economies goods become more

[46] The first big oil crisis was a direct result of the oil embargo imposed by the members of the Arab Petroleum Exporting Countries (OAPEC) on the United States, most of Western Europe and Japan, due to their support of Israel in its conflict with Syria and Egypt. It lasted from the 17th of October until the 17th of May 1973 and caused oil prices to quadruple to nearly US$ 12 per barrel, resulting in high inflation and recession throughout the world, the effects of which were felt until the early 1980´s (Wikipedia 2006b).Many of the affected countries imposed price controls and rationing. The U.S. for example introduced an odd-even rationing system, where only people with an odd number plate could purchase petroleum on an odd-numbered day. The second oil shock occurred during the onset of the Iranian Revolution in 1979, when the country's oil sector was mostly damaged during the protests which eventually led to the overthrow of the Shah and to Ayatollah Khomeini seizing power. The resulting reduction in world oil production was only about 8.9% (Hamilton 2003) but widespread panic exacerbated the crisis. Queues appeared again in front of gas stations and price controls were administered in the US although this time methods of rationing were not used. When the Carter Administration lifted price controls in April 1979, the oil price shoot up to its all time high until early 2006 of $39.50 per barrel (Hamilton 2003)

complicated and specialised with each step of production. Hence it becomes impossible to determine what outputs will be produced with a given set of inputs. Hoover and Giarratani (1999 [1984]) provide the following example: Input coefficients may be legitimately used to determine the amount of steel needed to make one ton of nails. The production of nails does not allow large variations in terms of nature and quantity of inputs required for a given output. However if there is an extra ton of steel available it is problematic to predict whether it will be used to produce nails, steel sheets, automobiles or other steel products. Hence they conclude that output coefficients must be less reliable than input coefficients. Forward linkages and supply multipliers can therefore only "…be estimated … in relative impressionistic terms" (Hoover and Giarratani 1999 [1984], p. 150).

1.3.1.2 Joint stability of production and allocation coefficients

One of the first empirical applications of Ghosh´s proposed methodology can be found in Augustinovics' (1970) comparative study of the Hungarian economic structure. When analysing the stability of input coefficients b_{ij} and y_{it} and output coefficients a_{ij} and c_{sj} for the Hungarian economy 1959-1964, her results refute Ghosh´s argument about the former being more stable in a planned economy than the latter (Augustinovics 1970). Joint stability studies of this type compare the " *degree to which production coefficients of an input-output model approximate their original value after an application of either the production or allocation version of the model*"(Chen and Rose 1991, p. 28)[47]. Similar studies for capitalist economies by Ehret (1970) for Germany, Giarratani (1981) for the U.S. 1963-1967 and Bon (1986) disaggregated over 7 U.S. sectors for six time spans between 1947 and 1977, arrived at the same conclusion: temporal stability of input and output coefficients were of the same order of magnitude. Helmstädter and Richtering (1982; cited in: Oosterhaven 1988) even found output coefficients to be more stable for Germany than input coefficients. In other words there does not seem to be a systematic tendency of either supply or demand driven models to perform better in ex-post forecasts of production levels.

However, looking at the biproportional relationship between the matrix of technical production coefficients, **A**, and the matrix of allocation coefficients, **B**, shown in Eqs. (38) and (39), these results seem hardly surprising. Essentially both coefficients are derived from

[47] Note that Chen and Rose (1991) provide this as a definition of "relative joint stability" in distinction to "absolute joint stability", which they referred to as "the requirement that both production and allocation coefficients remain constant after an application of either the production or allocation version of the input-output model" (Chen and Rose 1991, p. 28). The latter is an ideal situation which bears little operational relevance.

the same matrix **Z**, divided by the same value **x**, either column or row-wise. Thus if there is instability in the column (demand) approach, then there will be instability in the row (supply) approach too and vice versa (Oosterhaven 1981; 1988). Only if sectors develop very unequally one might expect to find a notable difference in the stability between the two sets of coefficients (Oosterhaven 1988). From Eq. (39) it follows that each allocation coefficient b_{ij} has a corresponding technical production coefficient a_{ij} for each gross-output solution, given by Eq. (40) (provided that each element b_{ij} of **B** is constant). Eq. (40) indicates how a_{ij} is affected by a new gross output vector **x**. Only if x_i and x_j change in the same proportion, will a_{ij} remain stable and production functions will not be altered, i.e. will there be joint stability of production and allocation coefficients. Indeed, Chen and Rose (1985) formally established that Eqs. (38) and (39) can be transformed into Eqs.(41) and (42) below, if either of the two sets of coefficients is stable and the other is not.

(40) $a_{ij} = (x_i/x_j)\, b_{ij}$

(41) $\mathbf{A}_{t+1} = \hat{\mathbf{e}}\mathbf{A}_t\hat{\mathbf{e}}^{-1}$ for a stable **B**

(42) $\mathbf{B}_{t+1} = \hat{\mathbf{e}}\mathbf{B}_t\hat{\mathbf{e}}^{-1}$ for a stable **A**

(43) $\hat{\mathbf{e}} = \hat{\mathbf{x}}_{t+1}\hat{\mathbf{x}}_t^{-1}$

In order to test relative joint stability of theses coefficients in the case of a large supply disruption Chen and Rose (1985; 1991) applied the most rudimentary form of the supply driven model to the 34 sector IO table of the 1979 Taiwanese economy. They simulated a 50 percent reduction in the supply of aluminium. This product has been chosen because on the one hand it is a crucial input to Taiwan's significant metal, machinery, transport equipment and electrical supplies industries. On the other hand the country is almost entirely void of bauxite and therefore depends to a large extent on imports of both, bauxite and aluminium. Similarly to a study by Giarratani (1976), discussed below, they decided to exogenise the aluminium sector by transferring it to the primary input group. Equation (36) therefore is transformed into (44). The aluminium sector is removed from **B**, giving $\overline{\mathbf{B}}$ and the vector **x** and **w** are shortened accordingly to give $\overline{\mathbf{x}}$ and $\overline{\mathbf{w}}$ respectively. $\overline{\mathbf{w}}^{+alu}$ is the new primary input vector, which is obtained by adding the direct aluminum allocation vector $\mathbf{z}^{alu}$ to the primary input vector $\overline{\mathbf{w}}$. The elements of the former [z_{mj}^{alu}] denote the exogenous aluminium inputs to each individual sector j (for all i,j = 1,…, n−1). To distribute the reduced aluminium supplies according to pre-shortage levels they then calculate a_{mj} [Eq. (46)], where y_m equals total final demand of aluminium.[48] Equation (44) is then used to calculate a new set of gross outputs, which together with the constant allocation coefficients is used to compute a new set of intersectoral flows $\bar{z}_{ij}$ and new production coefficients $\bar{a}_{ij}$ (Chen and Rose 1985; 1991).

(44) $$\bar{\mathbf{x}}' = \bar{\mathbf{w}}^{+\text{alu}\,\prime}\left(\mathbf{I} - \bar{\mathbf{B}}\right)^{-1}$$

(45) $$\bar{\mathbf{w}}^{+\text{alu}\,\prime} = \bar{\mathbf{w}}' + \mathbf{z}^{\text{alu}\,\prime}$$

(46) $$a_{mj} = \frac{z_{mj}^{alu}}{\sum_j z_{mj}^{alu} + y_m} \qquad m \neq j$$

Chen and Rose (1986, 1991 p. 33) conclude from the results that production and allocation coefficients show "(…) remarkable stability for the case of a sizeable supply disruption" and that the use of the allocation model "(…) will not necessarily violate the basic production conditions of its conventional counterpart". According to Oosterhaven (1988) however it is evident from Eqs. (38) and (39) and from the fact that the exogenous change is rather minor to the Taiwanese economy, that changes in coefficients would be minor. Nevertheless Chen and Rose (1986, 1991) find a large number of positive changes of production coefficients throughout all sectors. This happens as sectors absorb the reduction of aluminium, while still employing all other primary and intermediate inputs. In reality the major aluminium using sectors would be expected to produce layoffs and reduce their orders of intermediate inputs from other sectors. No such thing is possible in the supply model. Recalculating the production coefficients with the new reduced outputs shows a proportional increase of inputs in most sectors from all other primary and intermediate inputs. This will occur irrespective whether the sectors' product is a substitute of aluminium, no substitute, or even a complement (Oosterhaven 1988, p. 211). Moreover total output of sectors producing the main substitutes for aluminium i.e. plastic and copper would be expected to increase in reality. The supply-side model however treats each sector indistinctly from these characteristics and reduces the output of all sectors.

The supply shock is spread out over all thirty-four sectors, which explains why the reduction of total gross output in the Taiwanese economy is only 0.6 % according to Chen and Rose (1986, 1991). The same exercise carried out via a demand reduction of 50% in the Leontief model would have caused a 50 % output reduction in all aluminium-using sectors plus the

[48] In the original text it is stated that the vector z_{alu} is made up of the elements a_{mj}, which does not make sense, as for Eq. (45) this would mean adding a vector of coefficients to a vector of values.

according indirect effect. Chen and Rose argue that this very fact is "(…) the beauty of the supply model – it indicates how a supply shock can be cushioned by maintaining stability in distribution patterns" (Chen and Rose 1991 p. 33). The authors interpret the working behind this "cushion" on the one hand as a sign of increased productivity, where the new reduced supply of aluminium is used more efficiently. On the other side, and more importantly, it is assumed that the changes represent increased substitution of aluminium for other inputs. However, as the authors note themselves, the "*absurd machinations of the supply model*" (Chen and Rose 1986; 1991, p. 32) could result in such unrealistic substitutions as between transport and aluminium. Similar conclusions hold for the repetition of the Taiwan study for the US State of Washington (Allison 1989; Rose and Allison 1989). As will be shown in the following chapter, authors such as Oosterhaven (1981, 1988, 1989) have convincingly argued that the supply-driven IO model is simply implausible.

1.3.1.3 Empirical applications of the supply-driven IO model

There are currently two main applications of the supply-driven IO model: descriptive analyses of international comparison, forward linkages and key sectors and sectoral impact studies.

1.3.1.3.1 Descriptive studies

Augustinovics (1970) was among the first to use the supply-driven IO model for descriptive analysis. If interpreted carefully the Ghosh inverse and its derivatives can help to enhance our understanding of differing economic structures in different countries or regions and of differences between individual sectoral forward linkages (Oosterhaven 1988). Augustinovics (1970) designed the S x R matrix of Eq (47) to describe and compare the "*final allocation structure of primary inputs*" (Augustinovics 1970, p. 254) of Hungary and other European countries and the demand-side analogue to this which she refers to as "*primary input structure of final uses*" (Augustinovics 1970) [Eq.: (48)]. Oosterhaven (1988, p. 209) established that Eq. (47) represents the weighted final output multipliers for each individual primary inputs and Eq. (48) the weighted primary input multipliers for each individual final demand category. Augustinovics (1970) also showed how the supply-driven model can be used to avoid the price system in international and inter-temporal comparisons. As the model is based on allocation coefficients, which relate to one and the same product(s) or mix of products, it allows circumventing the valuation or pricing problems involved when using the demand-driven model for these studies.

(47) $\langle \mathbf{Wi} \rangle^{-1} \mathbf{W}(\mathbf{I}-\mathbf{B})^{-1}\mathbf{D}$

(48) $\mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{Y}\langle \mathbf{iY} \rangle^{-1}$

1.3.1.3.2 Forward linkage analysis

Forward linkage analysis is a more straightforward descriptive application of the supply-driven model and has been carried out for example by Giarratani (1976). He used the Ghosh-model to analyse (total) supply linkages[49] associated with US energy production and eventually to highlight the crucial position of the extractive energy sectors on the U.S. national economy. Just like in the traditional Leontief model, the relative importance of different economic sectors can be demonstrated by calculating their individual total[50] multipliers. Total output (or demand) multipliers are given by the column sums of the Leontief inverse $(\mathbf{I}-\mathbf{A})^{-1}$ [Eq.(49)], which can also be expressed in differential calculus as in the second part of Eq. (50). They indicate the total new output generated throughout all n sectors, if there were to be the equivalent of 1€ increase in the demand for the products of sector j. Row sums of $(\mathbf{I}-\mathbf{A})^{-1}$ are less popular for analysis but can be interpreted as showing the total increase of output necessary in sector i if all n sectors of an economy were to see their final demand increase by 1€ [Eq. (52)].

(49) $\mathbf{i'}(\mathbf{I}-\mathbf{A})^{-1}$ ....or…

(50) $$\sum_{i=1}^{n} a_{ij} = a_{1j} + a_{2j} + \ldots + a_{ij} + \ldots + a_{nj} = \left(\frac{\partial x_1}{\partial y_j} + \frac{\partial x_2}{\partial y_j} + \ldots + \frac{\partial x_i}{\partial y_j} + \ldots + \frac{\partial x_n}{\partial y_j} \right)$$

(51) $(\mathbf{I}-\mathbf{A})^{-1}\,\mathbf{i}$ …or…

(52) $$\sum_{j=1}^{n} a_{ij} = a_{i1} + a_{i2} + \ldots + a_{ij} + \ldots + a_{in} = \left(\frac{\partial x_1}{\partial y_i} + \frac{\partial x_2}{\partial y_i} + \ldots + \frac{\partial x_j}{\partial y_i} + \ldots + \frac{\partial x_n}{\partial y_i} \right)$$

(53) $(\mathbf{I}-\mathbf{B})^{-1}\,\mathbf{i}$ …or…

(54) $$\sum_{j=1}^{n} q_{ij} = q_{i1} + q_{i2} + \ldots + q_{ij} + \ldots + q_{in} = \left(\frac{\partial x_1}{\partial w_i} + \frac{\partial x_2}{\partial w_i} + \ldots + \frac{\partial x_j}{\partial w_i} + \ldots + \frac{\partial x_n}{\partial w_i} \right)$$

(55) $\mathbf{i'}\,(\mathbf{I}-\mathbf{B})^{-1}$ …or…

(56) $$\sum_{i=1}^{n} q_{ij} = q_{1j} + q_{2j} + \ldots + q_{ij} + \ldots + q_{nj} = \left(\frac{\partial x_j}{\partial w_1} + \frac{\partial x_j}{\partial w_2} + \ldots + \frac{\partial x_j}{\partial w_i} + \ldots + \frac{\partial x_j}{\partial w_n} \right)$$

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[49] (Total) forward supply linkages and (total) input multipliers are going to be used indistinctively in this text. Similarly no distinction is made here between (total) backward linkages and (total) output multipliers.

[50] In deviation of the terminology used in Miller & Blair 1985, the most comprehensive and widely used IO textbook, the word "total" is inserted here. This is to introduce a distinction between row or column sum multipliers and the individual values q_{ij} of $\mathbf{Q}$ which could also be regarded as multipliers.

The analogue to total output multipliers i.e. the column sums in the standard model are represented by the total input (or supply) multipliers in the Ghosh model. They are derived by building the row sums of **Q**, as shown in Eq. (53). Total input multipliers represent the effect on total output of all sectors of the economy, given a 1€ change in the primary inputs to sector *i*. According to Oosterhaven (1981), Beyers (1976) appears to be the first one who correctly used Eq. (53) to calculate forward linkages instead of using the inadequate row sums of the Leontief inverse as in other studies before. Total input multipliers could for example be used to determine, which sector would generate most additional output if given one extra unit of a scarce resource (Miller and Blair 1985). Oosterhaven (1988) however calls for caution in terms of any causal interpretations of the results obtained through Eq. (53). He claims that there is not the slightest relation between a sectors' total input multipliers (of primary supply) and the change in total production caused by a unit change of primary input in that sector. Assuming real output effects in other sectors, depending on the total input multipliers means disregarding the processing coefficients $1/a_{ij}$, described below, and also means disregarding any substitution possibilities. Column sums of **Q**, the parallel to row sums of $(\mathbf{I}-\mathbf{A})^{-1}$, indicate the effect on sector *j* if there were a 1€ change in the supply of primary inputs throughout all *n* other economic sectors [Eq. (55)].

Giarratani (1976) proposed this kind of analysis in order to evaluate alternative petroleum-distribution plans in case of shortages. He calculated **Q** and its row sums for the 78-sector US inter-industry table and then ranked the sectors accordingly. Total supply multipliers ranged from as high as 4.01 for sector 5 (iron and ferroalloy ores mining) to as low as 1.09 for medical, educational services and non-profit organizations. With respect to the former, this means that a shortage of primary inputs to sector 5 can have a four-fold effect on the national economy. Giarratani's (1976) results highlight the relative importance of the extractive sectors of the US economy. Among the top ranking sectors are the extractive energy sectors of coal mining (sector 7) on position nine and crude petroleum and natural gas exploitation (sector 8) on position eleven, which both have input multipliers of around 3.[51]

In continuation Giarratani (1976) looks at the individual inter-industry linkages (or supply multipliers) between the two extractive energy sectors as above, the only secondary energy sector in the table – petroleum refining – and all other 78 industries i.e.: $q_{i,7}$, $q_{i,8}$ and $q_{i,31}$,

[51] Somewhat surprising is the ranking of the radio and TV broadcasting sector, which comes third; a curiosity which remains unexplained in Giarratani's (1976) work.

where (i= 1, 2, …, 78). Linkages for coal mining seem almost insignificant, exhibiting merely for one sector a coefficient higher than 0.02 ($q_{45,7}$ – construction, mining and oil-field machinery).[52] Only slightly higher coefficients were found for crude petroleum and natural gas, where four supply industries show multipliers of over 0.02.[53] This does not seem surprising, since the extractive sectors are by definition at the bottom of the supply chain and are bound to be less dependent on supplies from other industries. For the petroleum refining sector this is different. Several industries which sell to this sector have supply multipliers of more than 0.04 e.g.: crude petroleum and natural gas, 0.86; maintenance and repair construction, 0.05, chemicals and chemical products, 0.051. In other words, for every unit of changed primary input to Crude Petroleum and Natural Gas Exploitation, the output of the petroleum refining industry will incur a change of output of 0.86 units. Disruptions in primary inputs to these sectors could therefore potentially have significant implications on the output of refined petroleum.

In order to relate value-added changes in supplying sectors to final energy use, one could calculate the final use coefficient vector **d** (vector of *row* sums of matrix **D**) as in Eq. (57), diagonalise it and post-multiply it with **Q** [Eg. (58)]. Elements of the resulting matrix would indicate total final use in sector j allowed by an extra unit of value added in sector i. Giarratani (1976) however argues that in the event of extreme shortages it may be inappropriate to treat the production of a scarce resource as endogenous. Petroleum could be regarded as the single most important non-renewable natural resource for western economies. The first Oil shock in 1973 caused mayor economic disruptions throughout the world and concerns about the finiteness of this resource were raised. Giarratani's (1976) work shows the engagement of the scientific community with this issue. Thus it is understandable that he chooses to exogenise the energy sectors including the two petroleum-related sectors (crude petroleum and natural gas and petroleum refining and related industries).

(57) $$\mathbf{d} = (\hat{\mathbf{x}})^{-1}\mathbf{y}$$

(58) $$\mathbf{Q}\hat{\mathbf{d}}$$

[52] Quite remarkable is the "self-linkage" of the coal sector ($q_{7,7}$ = 1.147), which is far higher than for the other two energy sectors ($q_{8,8}$ = 1.03; $q_{31,31}$ = 1.0847). In monetary terms this means that a reduction of 1€ worth of available primary input to coal mining, would cause a 1.147 reduction in output of the sector itself.

[53] e.g.: Maintenance and repair construction, 0.03; Machine shop products, 0.026:

Giarratani's (1976) proposed methodology for this purpose is to delete these sectors from the **B** matrix, giving $\overline{\mathbf{B}}$; augment vector **w** to $\overline{\mathbf{w}}^{+\text{energy}}$ which includes a vector of exogenous energy inputs [$\mathbf{z}^{e}$] [Eq.(59)] and carry out the calculation of (36) once more. Vector $\mathbf{z}^{e}$' in Eq.(59) represents exogenous energy inputs to industrial sectors [for all *i, j* = 1,..,*n*−2]. The length of both, vector **w** and the gross output vector **x**, will have been reduced by the two exogenised sectors, giving $\overline{\mathbf{w}}$ and $\overline{\mathbf{x}}$. Equation (36) will thus take the form of (59).

(59) $$\overline{\mathbf{w}}^{+\text{energy}\prime} = \overline{\mathbf{w}}' + \mathbf{z}^{e\prime}$$

(60) $$\overline{\mathbf{x}}' = \overline{\mathbf{w}}^{+energy\prime}\left(\mathbf{I} - \overline{\mathbf{B}}\right)^{-1}$$

With this framework, so Giarratani (1976), one could evaluate different allocation (rationing) programmes, for example one which is based on pre-shortage proportions $\vec{a}^{e}{}_{i}$ as in Eq. (61). The total output generated in each sector, *j*, by one unit of petroleum production distributed on this basis, would therefore be given by $\overline{\mathbf{x}}^{\text{rationing}\prime}$ of Eq. (61) i.e. the column sum of the matrix in Eq. (63). Row sums of this matrix on the other hand, represent the total output made possible in the economy when sector *i* receives its share of petroleum. According to Giarratiani (1979) both values could be useful for choosing between alternative rationing plans.

(61) $$\vec{a}^{e}{}_{i} = \frac{z_i^{e}}{\sum_i z_i^{e} + y_e}$$ [y_e.... column sum - final petroleum use]

(62) $$\overline{\mathbf{x}}^{rationing\prime} = \vec{\mathbf{a}}^{e\prime}\overline{\mathbf{B}}$$ which is equal to the column sums of matrix

(63) $$\hat{\vec{\mathbf{a}}}^{e}\,\overline{\mathbf{B}}$$

In his (1988) critique of the supply-driven model Oosterhaven firstly argues that Giarratani's (1976) use of total forward linkages in order to establish the crucial position of the extractive energy sectors is not wrong, if the results are interpreted loosely. Secondly however, Giarratani's causal interpretation of the supply multipliers and the procedure of omitting the energy sectors from the **B** matrix is "definitely incorrect as this procedure, inter alia, disregards the working of the processing coefficients" (Oosterhaven 1988, p. 211). As will be further discussed in section 1.3.1.4.1 unterhalb, the supply-driven model systematically underestimates direct and indirect forward linkages. A negative conclusion with regards to the application of supply multipliers is also reported by Cella (1988), who states that "…

exercises using supply multipliers to substitute demand multipliers can hardly be considered as giving meaningful conclusions" (Cella 1988, p. 448).

1.3.1.4 The plausibility of the Supply-Side I-O Model

Oosterhaven (1981, 1988) argues that given that empirical studies have failed to provide evidence for the superiority of either of the models, one has to turn to theoretical reasoning. In his paper "Plausibility of Supply-Side I-O Models" (1988) and in an earlier publication (1981), Oosterhaven concludes that the Ghosh model has to be rejected due to its implausibility. The fundamental problem rests within the models' assumption of perfect elasticity of demand, which means that **y** (final consumers, investment, etc.) will adapt smothely to any changes in supply. It ignores important interdependencies between certain products, such as it is very unlikely that sales of cars, to choose one example, would increase if there was not enough fuel available.

This becomes even more unrealistic when looking at inter-industry demands (z_{ij}). Oosterhaven (1988, p. 207) argues that in this case " … input rations vary arbitrarily and may in principle , assume any value depending upon (again) the availability of supply". Hence "the essential notion of production requirements, i.e., the production function, is actually abandoned" (Oosterhaven 1988, p. 207). An increase of availability of factory workers to a steel producer, for example, would directly result in an increase of steel being manufactured, even if there was no increase in the amount of available iron ore. Moreover indirectly this will cause an increase in output in all sectors purchasing from the steel sector. The supply model will effectively alter the production functions of these sectors, to distribute the additional steel throughout the economy. Each sector will increase its steel uptake according to proportions prior to the supply increase i.e. the allocation coefficients. This completely disregards the fact that a car manufacturer, for example, will not be able to build more cars just from the additional steel without increasing other primary inputs (e.g. labour, capital, etc.) or intermediate inputs supplied by other sectors (e.g.: tyres, windscreens, etc.).

Ghosh (1958) recognized the problem of relative instability of production functions, but did not consider it as a serious problem due to substitution possibilities. Chen and Rose (1985) however made the point that Ghosh (1958) is overly optimistic about these possibilities for two reasons: On the one hand substitution possibilities will be smaller over the short run than over the long-run, because new input combinations will have to be discovered and new technologies developed. The allocation model however has found many applications, in particular in the 70ies and 80ies, for analysing short-run disruptions to supply of certain resources. On the other hand Chen and Rose (1985) emphasise that nothing seems to suggest that the changes in production coefficients, caused by fixed allocation coefficients, could be "*random, inefficient, or even beyond the range of substitution possibilities*" (Chen and Rose 1985, 1991, p. 26).

Gruver (1989) showed that these changes are in fact not random or technically inefficient[54] in an obvious manner. He proves Oosterhaven's (1988) statement above, regarding the abandonment of the essential notion of a production function, to be incorrect, by describing a production function which is consistent with the assumption of fixed allocation-coefficients of the supply-driven model. This production function is derived from Eq. (6) above and given by Eq. (64). If divided by x_j, we get the individual output coefficients, the sum of which must equal to one [Eq. (65)]. This condition must hold in the demand-side model, but also in the supply side model. Whereas in the former production coefficients are assumed fixed, they are variable in the latter. Hence it follows that in the supply-driven model any decrease in intermediate (z_{ij}) or primary inputs (w_{sj}) will be compensated for by an equal increase of other intermediate or primary inputs. This implies that all inputs in all industry production functions have to be perfect substitutes i.e.: there has to be "infinite elasticity of factor substitution between each input pair" (Gruver 1989, p. 443).[55] This is in general of course "…very unrealistic since it implies that all inputs are non-essential in the production process and that any input can be substituted for all others simultaneously" (Gruver 1989, p. 449). Moreover if perfect substitution existed it would imply that given the behavioural assumption of cost-minimization, industries would, depending on relative prices, either always choose to have only one input (the cheapest) or input combinations would not be unique. The very opposite is true in the standard Leontief model, where one fundamental assumption is zero factor substitutability for all inputs.

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[54] Grover (1989, p. 444) uses a traditional concept of efficiency in production given for example by Varian (1984, p.9) here, which means it is "not possible to produce more with the same inputs or to produce the same amount with less of one and no more of any of the other inputs".

[55] As unrealistic this may appear here, the reader should be aware that perfect substitutability of the factors of production is in fact one of the fundamental assumptions in neoclassical economic theory and one which is being continuously criticized by ecological economists. An often quoted example, brought forward by Daly and Cobb (1989), is one of a chef baking a cake. Perfect factor substitution suggests that the cake can get bigger and bigger if only the chef stirred faster or if only the size of the oven was increased enough.

(64) $$f(z_{1j},...,z_{nj};w_{1j},...,w_{nj}) \equiv \sum_i z_{ij} + \sum_s w_{sj}$$

(65) $$\sum_i \frac{z_{ij}}{x_j} + \frac{w_{sj}}{x_j} = \sum_i a_{ij} + \sum_s c_{sj} = 1$$

In order to illustrate his critique of the supply-driven model further Oosterhaven (1981, 1988) alludes to the economic interpretation of the Taylor-expansion reproduced in Eq. (66), which equals the Ghosh Inverse (36) for $(n \Rightarrow \infty)$. Because of what has been established in (41) and (42), it seems appropriate to test the viability of the model assuming extreme uneven sectoral growth. Taking an increase of primary inputs worth, say, 1 Million €'s in only the first sector (w_1), the model produces the following results: Firstly outputs in sector 1 are directly increased by 1 Mill. €, due to the first term of the Taylor Expansion (**w'I**). [See Eq. (67) for an illustration of the 3x3 case]. This additional output is produced without any additional intermediate inputs from other sectors. What's more, if only one primary input w_{sj} e.g. labour is increased by 1 Mill. €, then the additional output in sector 1 is produced not only without additional intermediate inputs from other sectors but even without using other additional primary inputs e.g. capital, land, etc.

Secondly, the first-round indirect (forward linkage) production effect, represented by the second term of the Taylor expansion (**w'B**), provides an increase of the output of all sectors that purchase from sector 1 according to their corresponding allocation coefficient [compare Eq. (68)]. Once again this increased output is possible without any increase of intermediate inputs from other sectors i.e. sector 2 and 3 in the example below. Moreover these outputs materialise without any increase in value added (i.e. labour, capital, etc.), as these are exogenously given (Oosterhaven 1981, 1988). As all the following rounds finish simultaneously, the last increases of Z might be slightly less unreasonable than the first one, because more intermediate inputs become available. Nevertheless there might still not be sufficient inputs in all sectors for their production. Finally all the output generated throughout the following round-effects also forgoes increases in value added, which remains "*completely implausible*" (Oosterhaven 1981, p. 141; 1988, p. 207).

(66) $$\mathbf{x'} = \mathbf{w'I} + \mathbf{w'B} + \mathbf{w'B}^2 + \mathbf{w'B}^3 + \ldots + \mathbf{w'B}^n$$

(67) $$[\Delta x_1, x_2, x_3]^{direct} = [\Delta w_1, w_2, w_3] \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [\Delta w_1, w_2, w_3]$$

(68)
$$[\Delta x_1, \Delta x_2, \Delta x_3]^{first-round} = [\Delta w_1, w_2, w_3] \times \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} =$$
$$[(\Delta w_1 b_{11} + w_2 b_{21} + w_3 b_{31}), (\Delta w_1 b_{12} + w_2 b_{22} + w_3 b_{23}), (\Delta w_1 b_{13} + w_2 b_{23} + w_3 b_{33})]$$

Oosterhaven's (1988) critique triggered a vivid discussion in a later volume of the Journal of Regional Science. Gruver (1989) largely agrees with his critique, insists however that it might be too early to reject the supply driven IO model entirely. In his view it could be an acceptable tool for analysing the effects of small changes. Moreover Gruver (1989) claims that these changes are far from being nonsensical (Oosterhaven 1988). They could be seen as the error between the real level of substitution and the one prescribed by the assumption of constant allocation coefficients as the production function (4-20) above serves as a linear approximation of the real non-linear production function. Rose and Allison (1989) arrived at similar conclusions by presenting some impact simulations with a table for the US state of Washington. It is argued that if the changes to input coefficients (i.e. to the production function) caused by the fixed output coefficients are within tolerable limits, the supply model may still be used. The justification for this argument by Gruver (1989) is however based on a trivial case characterised by a variety of assumptions, constant relative prices to be one of them. If relative prices are altered just a little, this justification disappears (Oosterhaven 1989) and the relative cheapest input will be used only (see the debate in Vol. 29 of the Journal of Regional Science for all the arguments by Oosterhaven, Gruver and Rose & Allison).

Despite the contributions made by Guver (1989), his approach to the supply-driven model can still not be seen as a pure opposite of the Leontief model (Oosterhaven 1989). The former explicitly assumes multiple outputs, while the latter assumes multiple inputs. Thus in order to derive the purely opposite Ghosh and the Leontief quantity models, one has to start from a production function which contains multiple outputs and inputs, as indicated in (69). Both models can be derived as a special case of Eq. (69)[56] given the assumptions provided in Table (5). Oosterhaven (1989) once more points out that *"(f)rom a plausibility point of view, the economic implications of the first and the last assumption of the supply-driven model are most ludicrous*" (Oosterhaven 1989, p. 62).
Figure 29 illustrates the production functions underlying the assumptions of both models respectively.

[56] In addition, Oosterhaven (1989) points to the fact that both models represent the extreme ends of the general equilibrium model.

(69) $f(x_1,\ldots,x_i, y_1,\ldots, y_j) = 0$

Common Assumptions	
perfect competition, profit maximizing firms,	
Assumption of Demand-Driven IO Models	**Assumptions of Supply-Driven IO Models**
For the individual firm: - a single homogeneous *output* (i.e. perfect substitution among all *outputs*) - given demand for *output* - multiple *inputs* x_J - fixed input ratios (i.e. perfect complementarity of *inputs* x_i) - given prices for *inputs* x_j - cost minimization derived demand for *inputs* x_j (i.e. backward linkages)	- a single homogeneous *input* (i.e. perfect substitution among all *inputs*) - given supply of *input* - multiple *outputs* x_i - fixed *output* ratios (i.e. perfect jointness of *outputs* x_i) - given prices for *outputs* x_i - revenue maximization - induced supply of *outputs* x_i (i.e. forward linkages)
For the economy: - exogenous final demand for *outputs* per sector - endog. intermediate demand for *outputs* per sector - perfectly elastic supply of every *input* x_j (i.e. no jointness in production, no bottlenecks in capacity)	- exogenous primary supply of *inputs* per sector - endog. intermediate supply of *inputs* per sector - perfectly elastic demand for every *output* x_i (i.e. no complementarity in consumption no income constraints)

Table (5): Assumptions of Leontief and Ghosh models
Source: Adapted from: Oosterhaven 1989, p. 62

Nevertheless there seems to be one specific case which could render the implausibility of the supply-driven model, exposed via direct and first-round effects above, somewhat less irrational. Considering an economy that experiences a shortage of primary inputs to one sector only, say sector 1 and all other sectors are hoarding labour, capital and intermediate inputs from all sectors except the first one. In other words sector one is the sole bottleneck of such an economy, a loosening of which would enable an increase in outputs throughout all sectors. In this specific case the backlog of hoarded primary and intermediate inputs would allow production functions to be maintained. Moreover, backward linkages, which are not taken account of in the supply-driven model, are indeed zero because of the backlog.

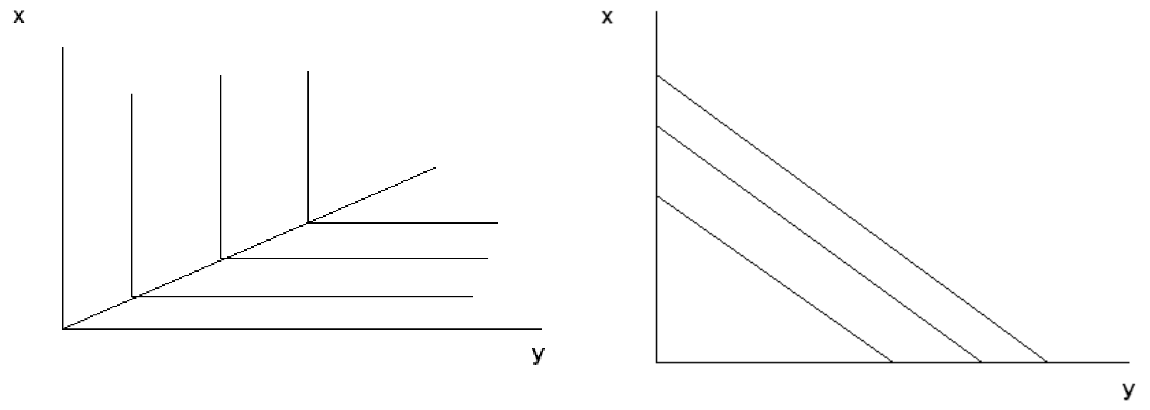

Figure 29: Production functions implied by Leontief (left) and Ghosh models (right)

At the first glance this case sounds like what could happen during supply restrictions of a key resource such as oil. Oosterhaven (1981, 1988), however shows that forward linkages are generally underestimated in the Ghoshian model. His arguments will be reproduced in the next Chapter. Moreover, the very same backlog would not allow higher order forward linkages (i.e. $\mathbf{w'B}^2 + \mathbf{w'B}^3 + \ldots + \mathbf{w'B}^n$), because there are already stocks of all other inputs waiting to be used i.e. they don't need to be produced anymore. It is unlikely that such backlogs can be built up during an oil shortage, as most intermediate inputs will need oil and energy themselves to be produced. Also assuming such a scenario would go against the very basic idea behind IO analysis, namely the way it shows how all industries are interlinked with each other and how an increase of an exogenous variable (be it demand or supply), causes direct and indirect effects throughout the economy. In conclusion Oosterhaven (1988, p. 208) argues that "*…both as a general description of the working of any economy and as a way to estimate the effects of loosening or tightening the supply of one scarce resource, the supply driven model may not be used*".

1.3.1.4.1 The Oosterhaven (1981) approach

As indicated above, Oosterhaven (1981) shows that forward linkages are underestimated in the supply-driven model. In his (1981) approach, which he characterizes as an elaboration and refinement of the Isard-Kuenne solution, he uses reciprocal coefficients from the regional attraction model put forward by Klaasen (1967; 1974), Klaassen and van Wickeren (1969) and Oosterhaven (1981,1988). The correct direct forward effect for sector one according to this approach is given by Eq. (71) and not just by w_1 as in Eq. (67). Equation (71) is obtained for (j = 1) by simplifying (15) oben to only one instead of s sectors and by making the according transformations shown in Eq. (70). ($1/c_1$) originates in the Walras-Leontief production function (18) and is described as the *reciprocal primary input coefficient*. It is a constant technical indicator and would denominate for example the feasible agricultural production per hectare (Oosterhaven 1981).

(70) $c_j = w_j/x_j \rightarrow x_j = w_j/c_j$ and for (j=1)

(71) $x_1^{direkt} = w_1(1/c_1)$

Eq. (68) above involves a similar underestimation and looking again at Eq. (18) it follows that the correct first-round forward indirect effects can be derived as in Eqs. (72) to (77). First x_j is expressed as a function of production coefficients (a_{1j}) [Eq.(73)] and intermediate outputs/inputs (z_{1j}) as a function of allocation coefficients (b_{1j}) [Eq. (75)]. Then z_{ij} in Eq. (73) is substituted by Eq. (75), to give Eq. (76) and (77). The expression ($1/a_{1j}$) in Eq. (77) is the *reciprocal technical output coefficient*, which would for example denote the amount of dairy products obtainable per unit of milk (Oosterhaven 1981). Hence Oosterhaven (1981,1988) also refers to the reciprocal coefficients as working-up or processing coefficients. Since b_{1j} and a_{1j} are constant, the maximum output which can be obtained in sector j is subject to condition (77) and depends on the output of x_1. This output in turn is subject to condition (70). Thus we have identified the two interdependent conditions of the Walras-Leontief production function

(16), which becomes (78) if i equals 1. It follows that in this case the maximum possible output of sector j is subject to the output minima inside condition (78).

(72) $a_{ij} = z_{ij}/x_j \rightarrow x_j = z_{ij}/a_{ij}$ and for (i=1)

(73) $x_j = z_{1j}/a_{1j}$

(74) $b_{ij} = z_{ij}/x_i \rightarrow z_{ij} = x_i b_{ij}$ and for (i=1)

(75) $z_{1j} = x_1 b_{1j}$

(76) $x_j = x_1 b_{1j}/a_{1j}$ which is

(77) $x_j^{first-round} = x_1^{direkt} b_{1j}\left(1/a_{1j}\right)$ (for $j \neq 1$)

(78) $x_j = Min\ (z_{1j}/a_{1j};\ w_1/c_1)$

Oosterhaven (1981), after finding all existing approaches unacceptable because of their contradictions and implausible assumptions, developed his own model for national and regional impact studies. It works in two phases, in the first of which it uses exogenous primary inputs and output coefficients from the supply-side model, combines it with the reciprocal coefficients discussed above and estimates the forward production effects. In a second phase, it systematically re-considers the input coefficients it used to estimate the backward production effects. Ex post input coefficients therefore become endogenous (See Oosterhaven 1981 p. 149ff and 1989 p. 212f for a more detailed description of the model). The model was then applied to estimate the employment effects of a new polder[57] in the Province of Friesland in northern Holland. Similarly to the aluminium studies mentioned above (Chen and Rose 1986, 1991; Allison 1989, Rose and Allison 1989) the change in agricultural output was bound to be negligible in relation to the existing agricultural output of the region. Thus the resulting change between the "pre-polder" and recalculated "post-polder" production coefficients (after the application of the supply driven model) would also be minimal, as they were in the studies above.

Contrary to what has been claimed by Rose and Allison (1989), Oosterhaven (1981) finds significant differences of normalized employment multipliers for the polder-project depending on which model is being used[58]. The *Oosterhaven-multiplier* is more than twice as large (2.8) as the pure supply-driven employment multiplier (1.38) on the national level. Despite its apparent soundness, the *Oosterhaven-model* requires, as its creator admits himself "…labour-intensive non-mechanical empirical research" (Oosterhaven 1989, p. 465) and no direct applications on the national or regional level seem to exist. Specialised models like this continue to be developed and applied e.g. Dietzenbacher and Gunluk-Senesen (2003), non of which however intend to measure the impacts of resource shortages.

1.3.1.5 The ongoing debate & conclusion

The debate about the plausibility of the supply-driven IO model calmed down after Volume 29 of the Journal of Regional Science, until a very convincing article by Erik Dietzenbacher (1997) in the same journal. Dietzenbacher (1997) argues that Oosterhaven's (1988) critique of the Ghosh model immediately disappears if it is interpreted as a price rather than a quantity

[57] "**Polder** is a low-lying tract of land that forms an artificial hydrological entity, enclosed by embankments known as dikes. Some need drainage by pumps to prevent the water table within it from rising too high. Some can be drained by opening sluices at low tide. The best-known examples are those polders that constitute areas of land reclaimed from a body of water, such as a lake or the sea, and are consequently below the surrounding water level." (Wikipedia 2006)

[58] Rose and Allison (1989) compared ordinary and *Oosterhaven (1981)-adjusted* production coefficients; recalculated after application of the supply-driven model to the Washington state table. They found only minor differences, which according to Oosterhaven 1989 is due to an incorrect application, failing to use Eq. (77) as well as (71).

model. This means that physical production functions will not be altered when value added for sector *j* is increased by one Euro, as quantities remain fixed in a price model. In other words the changes in output caused by changes in value added can meaningfully be seen as changes in value rather than quantity. Hence only the output value of sectors other than *j* will increase and the fact that value added remains unchanged is no more implausible.

Dietzenbacher then compares the Ghosh - and Leontief price model and shows that they deliver identical results. He concludes that the Ghosh price model provides small advantages over the Leontief price model, because it requires less information and computational steps. However, his findings are disputed in a conference paper by Ezra Davar (2005)who, after a lengthy mathematical and numerical treatment of the subject, concludes: " *(T)o replace Ghosh's quantitiative model with the Ghosh price model, as was suggested by Dietzenbacher, is both erroneous and unworthy of consideration*" (Davar 2005, p. 16).

This seems to be the last chapter that has been written in the controversy around the supply driven model. It is difficult to predict, whether alternative versions, which overcome its implausible assumptions will emerge in the future or if the model is just not salvageable. For now it has to be concluded that the ordinary supply driven IO model is inappropriate for the purpose of this study and model extensions such as the one offered by Oosterhaven 1981 are too data intensive and impractical.

1.3.2 Supply-constrained or mixed IO models

So far exogenous variables were either final demand [**Y**] in the demand-driven or value added [**W**] in the supply driven model. This restricts the scientific efforts to observe the impacts on total output [**x**] of either changes in final demand (e.g.: due to changing consumer tastes, government spending, etc.) or value added (e.g.: due to strikes, import embargoes, etc.) respectively. This is particularly restrictive for impact studies of supply shortages. For these studies it may be necessary to exogenise the sector which is potentially causing the disruption. Thus one would for example want to exogenise the output of a sector where the labour force of one of its major suppliers is on strike. Alternatively one could be looking at a planned economy, which aims at a certain percentage increase of the output of one of its sectors. With regards to the phenomenon of Peak Oil one would probably want to exogenise the whole energy sector or just the petroleum refining and extraction sector.

IO models with mixed exogenous and endogenous variables (therefore the name mixed models) provide a solution to this problem. In the literature they have firstly been described by Stone (1961, p. 98). Instead of estimating changes in sectoral outputs due to changes in final demand (traditional Leontief model) or value added (Ghosh model), mixed models estimate the impacts on unconstrained sectors given some reduced outputs of supply-constrained sectors. This approach allows the final demand of some sectors and gross output of the remaining sectors to be specified exogenously.

The procedure is best explained in terms of the three-sector economy of Table (3) above, which is going to be partitioned in constrained and unconstrained sectors as shown in Table (6) below. Provided the definition of production coefficients [a_{ij}] in Eq. (12) above, the basic linear IO relationships of Eq. (1), are given by Eq. (79) for our three-sector economy. Bringing sectoral outputs x_j to one side results in Eq. (80), which can then be rearranged into (81). Note that if expressed in matrix terms, Eq. (81) is simply $(\mathbf{I}-\mathbf{A})\mathbf{x}=\mathbf{Y}$ as in Eq. (22) above. In continuation it shall be assumed that total production of sector 3 (services), for whatever reasons this may be, will be determined by external forces. In other words sector 3 is subject to supply constraints. The exogenous variables of the system are therefore $\bar{y}_1$, $\bar{y}_2$ and $\bar{x}_3$ (marked with an over-bar above the variable), while x_1, x_2 and y_3 will be determined endogenously. As a next step all exogenous variables are brought to the right and all endogenous variables to the left hand side resulting in Eq. (82), which can be displayed in matrix form as in Eq. (83).

			Processing sectors			**Purchase Sectors**		**Total Out-put (x) (*j*)**
			non-constrained		**con-str'nd**	**Final Demand**		
		to (j) / from (i)	Agri-culture	Manu-facturing	Energy	House-holds etc.	Exports (**e**)	
Pro-cessing Sectors (Z) (*I* x *J*)	**non-constrained**	Agriculture	z_{11}	z_{12}	z_{13}	y_1	e_1	x_1
		Manufacturing	z_{21}	z_{22}	z_{23}	y_2	e_2	x_2
	constrained	Energy	z_{31}	z_{32}	z_{33}	y_3	e_3	x_3
Payments Sector (w)		Value added	w_1	w_2	w_3			
		Imports (**m**)	m_1	m_2	m_3			
Total Outlays (x') (*i*)			x_1	x_2	x_3			

Table (6): Partitioning the IO Table in constrained and unconstrained sectors[59]

[59] The annotation of this table slightly deviates from the basic table provided above for illustrative purposes.

(79) $x_1 = a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + y_1$
$x_2 = a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + y_2$
$x_3 = a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + y_3$

(80) $x_1 - a_{11}x_1 - a_{12}x_2 - a_{13}x_3 = y_1$
$x_2 - a_{21}x_1 - a_{22}x_2 - a_{23}x_3 = y_2$
$x_3 - a_{31}x_1 - a_{32}x_2 - a_{33}x_3 = y_3$

(81) $(1 - a_{11})x_1 - a_{12}x_2 - a_{13}\bar{x}_3 = \bar{y}_1$
$-a_{21}x_1 + (1 - a_{22})x_2 - a_{23}\bar{x}_3 = \bar{y}_2$
$-a_{31}x_1 - a_{32}x_2 + (1 - a_{33})\bar{x}_3 = y_3$

(82) $(1-a_{11})x_1 - a_{12}x_2 + 0y_3 = \bar{y}_1 + 0\bar{y}_2 + a_{13}\bar{x}_3$
$-a_{21}x_1 + (1 - a_{22})x_2 + 0y_3 = 0\bar{y}_1 + \bar{y}_2 + a_{23}\bar{x}_3$
$-a_{31}x_1 - a_{32}x_2 - y_3 = 0\bar{y}_1 + 0\bar{y}_2 - (1 - a_{33})\bar{x}_3$

(83) $$\underbrace{\begin{bmatrix} (1-a_{11}) & -a_{12} & 0 \\ -a_{21} & (1-a_{22}) & 0 \\ -a_{31} & -a_{32} & -1 \end{bmatrix}}_{\mathbf{M}} \times \begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} \bar{y}_1 + a_{13}\bar{x}_3 \\ \bar{y}_2 + a_{23}\bar{x}_3 \\ -(1-a_{33})\bar{x}_3 \end{bmatrix}$$

In order to be able to determine the values of the elements in the vector of endogenous variables (x_1,x_2,y_3), matrix **M** has to be transferred to the right hand side of Eq. (83) by building its inverse. Partitioning **M** reveals that the first quadrant is made up of the elements of (I−A) for the two sector case. The inverse of the partitioned matrix M can therefore be found as in Eq. (84), which allows rearranging Eq. (83) into Eq. (85). As a next step it is beneficial to manipulate the right hand side of Eq. (83), so that this equality can be rewritten as Eq. (86). Substituting the newly obtained matrix **N** into Eq. (85) will then read as Eq. (87). The new “double” matrix $\mathbf{M^{-1}N}$ can be interpreted as an expression that relates the exogenously determined variables $\bar{y}_1$, $\bar{y}_2$ and $\bar{x}_3$ with the endogenously determined variables x_1, x_2 and y_3. Thus it could be compared to the Leontief inverse in terms of representing the individual inter-industry output multipliers. In other words it expresses how the endogenous variables change, given a one unit change in the exogenous variables.

(84) $$\mathbf{M}^{-1} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \vdots & 0 \\ \alpha_{21} & \alpha_{22} & \vdots & 0 \\ \dots & \dots & \dots & \dots \\ \beta_1 & \beta_2 & \vdots & -1 \end{bmatrix}$$

(85) $$\begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \beta_1 & \beta_2 & -1 \end{bmatrix} \times \begin{bmatrix} \bar{y}_1 + a_{13}\bar{x}_3 \\ \bar{y}_2 + a_{23}\bar{x}_3 \\ -(1-a_{33})\bar{x}_3 \end{bmatrix}$$

(86) $$\underbrace{\begin{bmatrix} (1-a_{11}) & -a_{12} & 0 \\ -a_{21} & (1-a_{22}) & 0 \\ -a_{31} & -a_{32} & -1 \end{bmatrix}}_{\mathbf{M}} \times \begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & a_{13} \\ 0 & 1 & a_{23} \\ 0 & 0 & -(1-a_{33}) \end{bmatrix}}_{\mathbf{N}} \times \begin{bmatrix} \bar{y}_1 \\ \bar{y}_2 \\ \bar{x}_3 \end{bmatrix}$$

(87) $$\begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = M^{-1}N \begin{bmatrix} \bar{y}_1 \\ \bar{y}_2 \\ \bar{x}_3 \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \beta_1 & \beta_2 & -1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & a_{13} \\ 0 & 1 & a_{23} \\ 0 & 0 & -(1-a_{33}) \end{bmatrix} \times \begin{bmatrix} \bar{y}_1 \\ \bar{y}_2 \\ \bar{x}_3 \end{bmatrix}$$

If sector three, for example, was to experience an unavoidable reduction in output, this framework could be used to assess the impacts of this supply disruption on the rest of the economy. Provided the other exogenous variables remain unchanged (i.e. $\bar{y}_1$=0, $\bar{y}_2$=0 while $\bar{x}_3 = \downarrow$), Eq. (85) can be solved as Eq. (88). If only the reduced outputs $x_1\downarrow$ and $x_2\downarrow$are of interest, they can simply be found by reducing Eq. (88) to Eq. (89), because of how $\mathbf{M}^{-1}$ is structured. The vector on the far right hand side of Eq. (89) converts output of sector three into new demands of sector 1 and 2. The reduced total gross outputs from these sectors are then obtained by post-multiplying this new reduced demand with the Leontief inverse of the two-sector model.[60] The mixed model thereby satisfies changes in exogenous non-supply-constrained-sector final demand ($\Delta\bar{y}_1$ & $\Delta\bar{y}_2$) and/or exogenous constrained-sector supply ($\Delta\bar{w}_3$), through changes in unconstrained-sector-output (Δx_1 & Δx_2) and through changes in constrained-sector-imports (Δm_3) and -exports (Δe_3)[61] (Hubacek and Sun 2001).

(88) $$\begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \beta_1 & \beta_2 & -1 \end{bmatrix} \times \begin{bmatrix} a_{13}\bar{x}_3 \downarrow \\ a_{23}\bar{x}_3 \downarrow \\ -(1-a_{33})\bar{x}_3 \downarrow \end{bmatrix}$$

(89) $$\begin{bmatrix} x_1 \downarrow \\ x_2 \downarrow \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} \times \begin{bmatrix} \alpha_{12}\bar{x}_3 \downarrow \\ \alpha_{23}\bar{x}_3 \downarrow \end{bmatrix}$$

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[60] An alternative approach has been mentioned in Ritz and Spaulding (1975, cited in Miller and Blair 1985), which involves the calculation of output-to-output multipliers. These are obtained by dividing each "final-demand-to-output multiplier" αij by αjj, which results in a new Leontief inverse (I-A*) with elements αij*. Each of these elements "… in column j of (I-A*) indicates by how much the output of that sector (the row label) would change if the output of sector j changed by one dollar" (Miller and Blair 1985, p. 328). Post-multiplying (I-A*) by vector $\bar{\mathbf{x}}$, consisting of $\bar{x}_j$ (changed output of sector j) and zeros elsewhere, will then provide the changed output throughout the economy [i.e.: x = (I-A*) $\bar{\mathbf{x}}$]. This approach is basically equivalent to the one described above, but can be used with one exogenised sector only.

[61] This occurs via net-exports, which is part of final demand of the suppy-constrained sectors.

(90) $$\begin{bmatrix} \mathbf{x_{no}} \\ \mathbf{y_{co}} \end{bmatrix} = \begin{bmatrix} \mathbf{P} & \mathbf{0} \\ \mathbf{R} & -\mathbf{I} \end{bmatrix}^{-1} \times \begin{bmatrix} \mathbf{I} & \mathbf{Q} \\ \mathbf{O} & \mathbf{S} \end{bmatrix} \times \begin{bmatrix} \overline{\mathbf{y}}_{\mathbf{no}} \\ \overline{\mathbf{x}}_{\mathbf{co}} \end{bmatrix}$$

P…...	($k \times k$) matrix containing the elements from the first k rows and the first k columns in ($\mathbf{I}-\mathbf{A}$). It provides the average expenditure propensities of non-supply constrained sectors.
R…...	[$(n-k) \times k$] matrix containing elements from the last ($n-k$) rows and the first k columns of ($-\mathbf{A}$). It provides average expenditure propensities of non-supply constrained sectors on supply constrained sector output.
$\mathbf{x_{no}}$ ⋯	k-element column vector with elements x_1 through x_k; representing endogenous total output of non-supply constrained sectors.
$\mathbf{y_{co}}$ ⋯	($n-k$)-element column vector with elements y_{k+1} through y_n, representing endogenous final demand of supply constrained sectors.
Q…….	[$k \times (n-k)$] matrix of elements from the last ($n-k$) rows and first k columns of (**A**) and represents supply constrained sector expenditure propensities on non-supply constrained sector output.
S…...	[$(n-k) \times (n-k)$] matrix of elements from the last ($n-k$) rows and columns of $-(\mathbf{I}-\mathbf{A})$, and represents average expenditure propensities among supply constrained sectors.
$\overline{\mathbf{y}}_{\mathbf{no}}$ ⋯	k-element column vector of elements y_1 through y_k, representing exogenous final demand for non-supply constrained sectors.
$\overline{\mathbf{x}}_{\mathbf{co}}$ ⋯	($n-k$)-element column vector of elements x_{k+1} through x_n, representing exogenous total output for supply constrained sectors.

Table (7): Sub-matrices of equation (90)
Adapted from Miller & Blair (1985, p. 332) and Hubacek & Sun (2001, p. 332)

From Eq. (87) above one can develop the mixed model for the general case given in Eq. (90). There are now n total sectors of which one or more are exogenous. The sub-matrices of Eq. (90) are defined as in Table (7). The labeling of the sectors indicates that the first k sectors contain the endogenous elements and the last (n–k) sectors the exogenous elements.

The general case can also be arrived at as shown by Stone (1961) and Davis and Salkin (1984). It shall also be reproduced here, because it is not as lengthy and maybe more intuitive than the computations provided by Miller and Blair (1985). It explicitly uses partitioned Table (6) for the n total and k constrained case. Moreover this approach will also be used to illustrate how the supply driven parallel of the mixed Leontief model can be derived. Firstly the Leontief IO system represented by Eq. (20) is partitioned into ($n-k$) constrained and k unconstrained matrixes and vectors, as to obtain Eq.(91) (Stone 1961 p. 98-99). The annotation in this equation follows a similar logic as above, where $\mathbf{A_{k,(n-k)}}$, for example, represents the technical coefficients for the purchases of the unconstrained sectors from the constrained sectors. A dash on top of a letter indicates the fact that the variable is exogenous as before. Output of the k unconstrained sectors, can then be calculated by resolving and rearranging Eq. (91) into Eq. (92). Demand for the constrained sectors on the other hand is given by Eq. (93) after a similar process.

(91) $$\begin{bmatrix} \mathbf{x_k} \\ \cdots \\ \mathbf{\bar{x}_{(n\text{-}k)}} \end{bmatrix} = \begin{bmatrix} \mathbf{A_{k,k}} & \vdots & \mathbf{A_{k,(n\text{-}k)}} \\ \cdots & \cdots & \cdots \\ \mathbf{A_{(n\text{-}k),k}} & \vdots & \mathbf{A_{(n\text{-}k),(n\text{-}k)}} \end{bmatrix} \begin{bmatrix} \mathbf{x_k} \\ \cdots \\ \mathbf{\bar{x}_{(n\text{-}k)}} \end{bmatrix} + \begin{bmatrix} \mathbf{\bar{y}_k} \\ \cdots \\ \mathbf{y_{(n\text{-}k)}} \end{bmatrix}$$

(92) $$\mathbf{x_k} = \mathbf{A_{k,k}x_k} + \mathbf{A_{k,(n-k)}\,\bar{x}_{(n\text{-}k)}} + \mathbf{\bar{y}_k}$$

$$\mathbf{x_k} = (\mathrm{I} - \mathbf{A_{k,k}})^{-1}\,(\mathbf{A_{k,(n-k)}\,\bar{x}_{(n\text{-}k)}} + \mathbf{\bar{y}_k})$$

(93) $$\mathbf{\bar{x}_{(n\text{-}k)}} = \mathbf{A_{(n-k),k}x_k} + \mathbf{A_{(n-k),(n-k)}}\;\mathbf{\bar{x}_{(n\text{-}k)}} + \mathbf{y_{(n\text{-}k)}}$$

$$\mathbf{y_{(n\text{-}k)}} = (\mathrm{I} - \mathbf{A_{(n-k),(n-k)}})\;\mathbf{\bar{x}_{(n\text{-}k)}} - \mathbf{A_{(n-k),k}x_k}$$

As already mentioned, supply constraints can not only be incorporated into the demand driven, but also in the supply driven model [compare Davis and Salkin (1984)]. Following a similar procedure as above, Eq. (33) can be partitioned as indicated in Eq. (94). The values for the output of the unconstrained sectors and final demand of the constrained sectors can then be found via Eq.(95) and Eq. (96) respectively.

(94) $$\left[\mathbf{x_k} \;\vdots\; \mathbf{\bar{x}_{(n\text{-}k)}}\right] = \left[\mathbf{x_k} \;\vdots\; \mathbf{\bar{x}_{(n\text{-}k)}}\right] \times \begin{bmatrix} \mathbf{B_{k,k}} & \vdots & \mathbf{B_{k,(n\text{-}k)}} \\ \cdots & \cdots & \cdots \\ \mathbf{B_{(n\text{-}k),k}} & \vdots & \mathbf{B_{(n\text{-}k),(n\text{-}k)}} \end{bmatrix} + \left[\mathbf{\bar{w}_k} \;\vdots\; \mathbf{w_{(n\text{-}k)}}\right]$$

(95) $$\mathbf{x_k} = (\,\mathbf{\bar{x}_{(n\text{-}k)}\,B_{(k-n),k}} + \mathbf{\bar{w}_k}\,)\;(\mathbf{I-B_{kk}})^{-1}$$

(96) $$\mathbf{w_{(n\text{-}k)}} = \mathbf{\bar{x}_{(n\text{-}k)}}\;(\mathbf{I-B_{(n-k),(n-k)}}) - \mathbf{x_k\,B_{k,(n-k)}}$$

Oosterhaven (1989) raises the objection that primary inputs, which remain in the supply driven mixed model as a residual value equal to the difference between exogenous production and endogenous intermediate outputs, could theoretically assume a negative value. The same is apparently true for the final output of the sectors that have an exogenous production level in the demand driven variant applied by Davis and Salkin (1984). Miller and Blair (1985) also show how certain resulting elements of the demand driven mixed model can assume a negative value. Going back to the three-dimensional example above, looking at Eq. (85) and given the values for the a_{ij}'s, two properties of the system can be observed. Firstly, it is possible to solve the first two equations of (85) and find that if exogenously given $\bar{y}_1$, $\bar{y}_2$ and $\bar{x}_3$ are positive, then x_1 and x_2 will necessarily also be positive. Secondly it is clear that x_1 and x_2 are not influenced by y_3, while y_3 itself on the other hand is subject to the solutions of both,

x_1 and x_2. This fact has already been demonstrated in Eqs. (88) and (89) oben. Solving the third equation of (83) for y_3 gives Eq. (97), which is nothing more than the standard IO identity for sector three in a three dimensional model[62]. Equation (97) clearly illustrates the dependency of y_3 on x_1 and x_2. Moreover Eq. (97) demonstrates that y_3 is indeed found as a *residual*[63] in the system as Oosterhaven (1989) pointed out. Depending on the values of x_1 and x_2, which are subject to exogenous demand for sector one and two, and the exogenously determined value for $\bar{x}_3$, y_3 can be positive, zero or negative.

(97) $$y_3 = (1 - a_{33})\,\bar{x}_3 - a_{31}x_1 - a_{32}x_2$$

However Miller and Blair (1985) argue that there are a variety of explanations for negative values of this residual. Say, all variables are defined as "changes in". Hence a negative y_3 would imply that exogenous increases in final demand of sector one and two ($\bar{y}_1\uparrow, \bar{y}_2\uparrow$), without increasing exogenous total output of sector three ($\bar{x}_3\leftrightarrow$), is only possible by decreasing final demand in sector three ($y_3\downarrow$). Such a situation could arise in planned economies, where consumption of some goods have to be reduced in order to meet the production targets for another good. Similarly in the case of shortages of the exogenised sectors' output ($\bar{x}_3\downarrow$) due to natural disasters, trade barriers, strikes, etc., final demand for the products of that sector might have to be reduced. Secondly, even if variables are not defined as "changes in", there are other absolutely plausible explanations for a negative y_j. Exports, which are part of final demand, for example, could be interpreted as net-exports. In that case it follows that a negative y_j, indicate the fact that additional quantities of product *j* have to be imported (i.e. net-imports).

1.3.2.1 Previous empirical applications of "mixed models"

The earliest application of this approach known here can be found within the "empirical regional input-output projection model" for the US state of Washington put forward by Tiebout (1969). He projected and then exogenously specified the output of 13 out of a total of 57 sectors and determined the outputs of the remaining 44 sectors with the above method. Methodologically of particular interest is the paper by Davis and Salkin (1984), referred to earlier. As already mentioned they show how supply constraints can be incorporated in both, the Leontief and the Ghosh model. What's more they also close both models with respect to

[62] see third equation of (81)
[63] It is influenced by other variables, but does not influence them (Miller and Blair 1985)

households, in order "*to account for the Keynesian rounds of consumer spending*" (Davis and Salkin 1984, p 29). Closing the model means integrating households as an additional production sector. The row of that sector shows, as usual, the output of the sector (labour hours), while the column shows its inputs (consumption). As drivers for the model remain the remaining final demand (i.e. government spending, investment, etc.) and the remaining value added (capital, rent, profits, etc.), for the demand and supply driven models respectively.

Empirically Davis and Salkin (1984) applied both procedures to a fictional curtailment of governmentally subsidised water supply in one county of the US state of California. They circumvent the problem of integrating the resource 'water' into the IO model, by using secondary data from Noel (1981, cited by Davis and Salkin 1984). In this study a reduction of US$ 0.19 from US$ 1.34 billion[64] in agricultural output was estimated in case of such a "water cut-off". With this figure the authors were able to constrain the agricultural sector to a total of US$ 1.15 (1.34−0.19) in terms of output.

The results of the two methods differ quite substantially, with an estimated US$ 250 million reduction in the rest of the economy produced by the closed Leontief supply-constrained compared to a mere US$ 177 million reduction obtained via the closed Ghosh supply-constrained model. The authors attribute these findings to the strong backward linkages of the agricultural sectors in contrast to its relatively weak forward linkages. The petroleum sector for example accounts for a quarter of the total local purchases of the agricultural sector. The petroleum industry on the other hand has particulary strong backward links to the mining industry (crude petroleum). Since both of these sectors are the largest in the economy in terms of output it is not surprising that the measured total economy output reduction is substantial. Forward linkages of the agricultural sector within the regional economy are relatively small, mostly due to the fact that roughly three quarters of agricultural products are exported. Thus the reduction of agricultural output was to a large extent absorbed by a reduction of exports.

Oosterhaven (1989) objects to this application of the supply-driven model, for the reasons already mentioned above. In addition he points out that closing the Ghosh model with respect to households has even more implausible implications than in its original form. He provides the example of an increase of one million €s worth of shirts in the economy. This would mean

[64] In the paper, the authors quote a pre-water-cut-off output of 1.2 billion US$, which does not seem to add up to the figures of Table 1 on page 28 (Davis and Salkin 1984). Therein the total reduced post-water-cut-off agricultural output is given as 1148.18, which then sums up with 190.26 to 1338,44.

that the income of households would also increase by one million, "(…) which is of course ridiculous" (Oosterhaven 1989, p. 208). After allocating this increase to all sectors according to the historical allocation coefficients, then the resulting increase in household income (given that households are now also an "industry" sector), generates an equally large increase in spectral output. This fact leads the discussion back to Oosterhaven's (1989) claim that forward linkages are underestimated in the Ghoshian Model (see chapter 1.3.1.4.1).

Proceeding chronologically, a series of papers follow, which use the supply-constrained model in combination with a social accounting matrix (SAM). These matrixes have similar properties to IO Tables and a detailed description is beyond the scope of this thesis. Subramanian and Sadoulet (1990)were among the first to use the model in a SAM context and the ones who discussed the methodology in most detail. Similarly studies followed by Lewis and Thorbecke (1992) and Parikh and Thorbecke (1996). The overall setting for these papers is an estimation of the effectiveness of various policies to alleviate poverty in rural villages of the third world. Many analysts apparently believe that the assumption of excess capacity and perfect elastic supply in orthodox IO (SAM) models is unrealistic for the agricultural sector in the third world (Lewis and Thorbecke 1992). It follows that the traditional approach would generate highly inflated output and income multiplier estimates, predicting overly optimistic effects of stimulating policies.

Hence all of the above studies introduce supply constraints for the agricultural sector, thereby limiting the total agricultural output. This is an implicit tribute to the obvious fact that arable land is ultimately limited, not only in the third world.

Whereas the orthodox IO model allows stimulation of regional output and income only by increasing exogenous final demand, the mixed model distinguishes between "demand" and "supply driven"[65] sectors i.e. non-supply constrained and supply constrained (here agricultural) sectors. To stimulate the former, increases of exogenous demand is needed (e.g. increased government spending), while stimulating the latter requires increases of exogenous output (e.g. progress in agricultural techniques). Nevertheless, results have to be interpreted with caution and Lewis and Thorbecke (1992) admit that the "true" multiplier values will probably lie somewhere in between the results of the supply-constrained model and the traditional IO model.

[65] This description is not entirely correct, as the employed model is still using the A and not the B matrix and is therefore of course wholly demand driven.

On the same lines are the research efforts of Hubacek and Sun (2001). They explore the effects of limiting the supply of land for the mayor land consuming sectors in China. This makes perfect sense given the fact that only very little (14%) of Chinas vast 960 million ha of national territory, are cultivated with field crops and horticultural products. Moreover primary farmland together with most of its population (one billion of 1.3 billion) and economic activity is concentrated in less than one third of the land area. Thus sooner or later the availability of land may be one of several factors to place a strain on Chinas enormous annual GDP growth rate of 9.8% between 1978 and 1998.

Thus the authors intend to estimate Chinas land use and land cover change until 2025, using data from the base year 1992. For this purpose they combine biophysical, economic and societal data via a structural economics framework, at the hart of which is a supply constrained input-output model. The rational behind using the IO framework for estimating land use change is that basically all economic activities consume space. It follows that in the long-run, in order to increase output of one or more sectors significantly, there must be an increase or changes in land use, an increase in land productivity or an increase in imports (of land-intensive products). This rational delivers the basis for integrating land into the IO-model as explicit factor input.

China is, according to the authors, “(…)a group of co-evolving, disparate economies rather than a homogenous entity” (Hubacek and Sun 2001, p. 369), for which reason it is important to integrate both the national and the regional scale into such a study. Consequently Hubacek and Sun (2001) develop seven regional models and then a national one for China. In this way they can on the one hand model the effects of land-constraints on inter-regional trade of land-based products. On the other hand they were able to evaluate the degrees of land scarcity on both scales (regional and national) and the desired levels of land-productivity improvements.

The model they constructed consists of 11 sectors, whereby the land-intensive agricultural sector is divided into six sub categories. The strong biophysical linkages between land-use changes in economic sectors and those in land categories (i.e. cultivated land, grassland, forestland, etc.) are secured by pre-multiplying the vector of change in total output ($\Delta\mathbf{x}$)[66] with

[66] The change in total output $\Delta\mathbf{x}$ is caused by the change in final demand $\Delta\mathbf{y}$ and calculated as in the standard IO model and Eq. (25).

the diagonal land requirement coefficient matrix ($\hat{\mathbf{C}}^{\mathrm{LAND}}$) and the land distribution matrix (**R**) [see Eq. (84)]. The elements of **R** represent the mapping relationship between economic sector land uses and natural categories of land cover. Land requirement coefficients associated with economic activities j ($c^{LAND}{}_{j}$), are produced by building the ratio of total sector land use (l_j)[67] to total sectoral output [see Eq. (99)]. This ratio is in fact the inverse of sectoral land productivity $p^{LAND}{}_{j}$, which is defined as the output in monetary terms (here Yuan) produced on one ha land. The total future land requirement is then attained by building the sum of the land required for the additional output $\Delta\mathbf{x}$ and the historic land requirements of 1992 as shown in Eq. (100).

(98) $$\Delta \mathrm{l} = \mathbf{R}\hat{\mathbf{C}}^{\mathrm{LAND}}\Delta\mathbf{x}$$

(99) $$c^{LAND}{}_{j} = \frac{l_j}{x_j} \quad ; \quad p^{LAND}{}_{j} = \frac{x_j}{l_j}$$

(100) $$\mathrm{l}^{2025} = \mathrm{l}^{1992} + \Delta \mathrm{l}$$

The above simple model was then modified to take account of the fact that sectors might not be able to increase at will their land "consumption" in correspondence with their increases in output. In such a case the traditional demand driven IO model, would generate unrealistically large multiplier estimates. Hubacek and Sun (2001) therefore decided to constrain the major land-use sectors (grains, other crops, forestry and livestock), based on the intuitive assumption that other economic sectors would find it easier to satisfy their additional land requirements. The modified model is given by Eq. (90) above and in addition Hubacek and Sun (2001) defined and calculated the potential net-export (**t**) of supply-constrained sector products as the difference between exogenous and endogenous final demand of these sectors. The potential exogenous output ($\mathbf{x_f}$) of the supply-constrained agricultural sectors was then found by dividing the land per land-use category available in 2025 ($\bar{\mathbf{l}}_{\mathbf{f}}$) by the respective future land requirement coefficient ($\mathbf{c_f}$). That is, taking into account the projected land productivity and availability and the increases of final demand caused by changes in the economy and society, the additional required net import of land-based products will be given by the balancing of the IO model.

(101) $$\mathbf{t} = \bar{\mathbf{y}}_{\mathbf{co}} - \mathbf{y}_{\mathbf{co}}$$

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[67] The annotation has been adapted in conformity with the convention set out in footnote 3.

(102) $$\mathbf{x_f} = \frac{\bar{\mathbf{l}}_\mathbf{f}}{\mathbf{c_f}}$$

The exogenously generated potential output ($\mathbf{x_f}$), the regional differences for the land requirement and land productivity coefficients, as well as other necessary biophysical data were obtained via Agro-Ecological Zone (AEZ) assessment, which is based on information supplied by Geographical Information Systems (GIS). Land use per economic sector was developed from data available in the IIASA-LUC database[68]. In terms of future production, certain key cells of the future technical coefficients matrix (e.g.: $a_{Grains,Industry}$) were estimated with the case study methodology developed and applied by Duchin and Lange[69]. The remaining coefficients were computed using the RAS method[70]. In continuation, for estimating land use change, they developed 6 scenarios, based on its major driving forces: economic growth/per capita income growth; population expansion; urbanisation; changing consumption patterns, technological change and land productivity. The results of the model show that by 2025 China will most likely not be able to satisfy its demand for land-based products unless it increases significantly its land productivity or its imports (Hubacek and Sun 2001). Looking at the necessary annual growth rate of land productivity reveals numbers for some products that are unheard of in the literature. Moreover the necessary imports in order to satisfy the projected demand are, for some products, beyond the capacity even of world markets.

1.3.2.2 Conclusion

After reviewing the methodology, literature and empirical applications of the supply constrained IO models it has become evident, that it is a prime candidate for analyzing supply shortages of certain sectors. The methodology is sound and straight forward, the literature does not hold any fundamental criticism of the model like in the case of Oosterhaven (1988) and the supply-driven model and empirical applications have produced useful results. Most of these empirical studies use the method to incorporate the absolute scarcity of available land in a country and of course on planet earth. This has been achieved by exogenising the output of the agricultural sector. In order to measure the potential effects of Peak Oil for an individual

[68] „A number of fairly large and detailed geographical databases on China, including biophysical attributes of land and statistical data at the country level, have been implemented in the LUC geographical information system." (Hubacek and Sun 2001, p. 377)
[69] Compare Duchin et al. (1993); Duchin and Lange (1992, 1994); all cited in Hubacek and Sun (2001).
[70] Compare Budavari (1981, p. 404 cited in Hubacek and Sun 2001) and Miller and Blair (1985, p. 276) for description and applications of this method.

economy, one would have to find the sectors which introduce the resource into the economy. For the empirical analysis which follows below, the two sectors of "petroleum & natural gas extraction" and "petroleum refining" were selected to be exogenised. Beforehand the Leontief price model shall be reviewed. Whereas the supply constrained model will be used to analyse the quantity side of Peak Oil, the price model could provide a framework for taking account of the price dimension of Peak Oil in future studies.

1.3.3 Empirical application of the Supply-Constrained IO Model

Because of the reasons described above, a mixed model has been chosen for a first cautious empirical analysis. In order to learn more about the effects of the specific problem of Peak Oil, the sectors "crude petroleum and gas extraction" and "petroleum refining" were subjected to a hypothetical reduction of total output of ten percent each.

1.3.3.1 Scenario selection

The 10% reduction is a random choice but is in about the same range as the shortfall of oil production during past oil shocks as illustrated in Chapter 2.2 (Part 1). However, for reasons which will be further alluded to below, it is the rankings of the affected sectors, rather than the actual magnitudes of output reductions that are considered of interest here. Hence the actual percentage of the output reduction is not of great importance.

1.3.3.1.1 Domestic oil flows

The decision to reduce the output of both, oil and gas extraction and petroleum refining was taken in order to capture most of the oil flows within the analysed economy. As shown in Figure 30 below domestic oil consumption manifests itself in three different ways (crude oil, refined petroleum, embodied crude oil), each of which can be attributed to either foreign or domestic production. Since this analysis is restricted to the national level, it does not take account of all the flows indicated with arrows in Figure 30. Fully and directly captured are only those flows, indicated with dark grey arrows i.e.: domestic crude oil and refined petroleum products. Indirectly this also accounts for domestic crude oil used for petroleum refining and crude oil and refined petroleum products used as inputs for domestic goods.

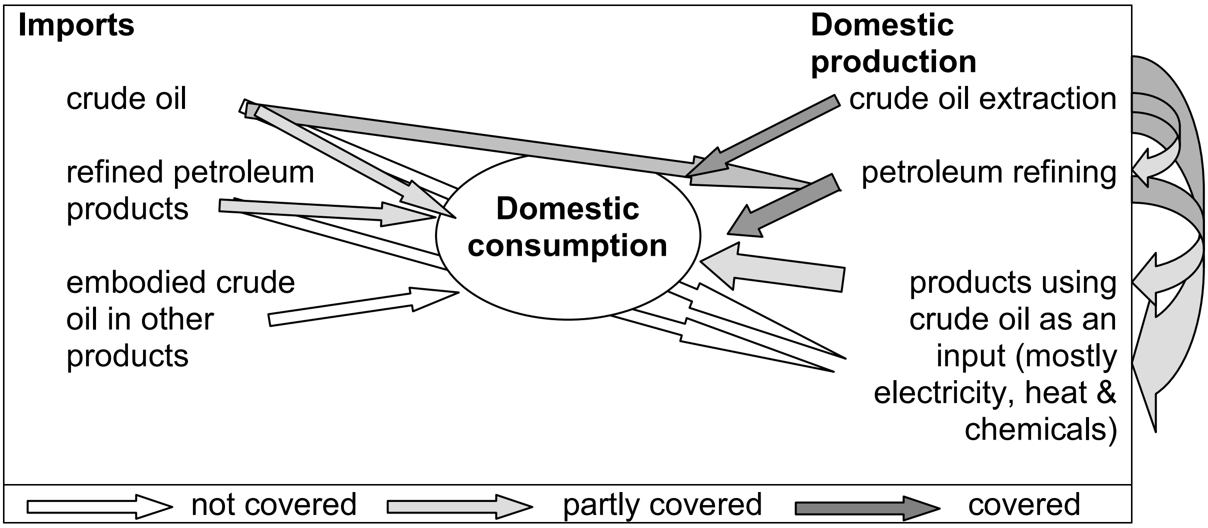

Figure 30: Sources of domestic oil consumption.

Imports of crude oil and refined petroleum products, which are then used as inputs for domestic products (other than refined petroleum products), and crude oil embodied in other imported products, on the contrary, are not captured by this procedure. A light grey arrow is therefore used to mark the only partially captured oil flows from domestic oil-containing products to domestic consumption. The white arrows on the other hand indicate flows that are not accounted for at all. Depending on the country these unaccounted flows will vary, are however expected to be significant and are bound to cause an underestimation of the true effects of a world oil production decline for an economy. Peters and Hertwich (In Press) recently determined the CO_2 emissions embodied in Norwegian imports. These embodied emissions can give some idea about the magnitude of embodied oil in imports too, as they mostly originate from fossil fuels. Peters and Hertwich (In Press) found that 67% of Norway's emissions can be attributed to imports. Future research of this type will therefore have to adopt a more international perspective, which is at this point still problematic because of data availability. Nevertheless, the purpose of this research is, as already mentioned, not so much to deliver final qualitative results, but to provide an overview of different models and to run a first test with the most attractive one.

1.3.3.1.2 Backward and forward linkages of the oil sectors

It should be noted that the crude oil extraction sectors' largest customer is usually the petroleum refining sector and the other way around the petroleum sectors' largest supplier is the crude oil extraction sector. This can easily be shown by calculating the respective direct forward and backward linkages. Linkages for the UK, Japan and China are given in Table (8). The direct backward linkage indicates how many €'s worth of inputs from oil and gas extraction are necessary per one € worth of total output from the petroleum refining sector, this is of course the corresponding entry in the **A** matrix. The direct forward linkage on the other hand describes how many €'s worth of output are generated in the petroleum refining sector, if total outlays of the crude oil and gas extraction sector are increased by one €, which is the corresponding entry in the **B** matrix. As it can be seen in Table (8) below, direct backward linkages are remarkably similar for Japan, the UK and China, they are all around 0.4. The direct forward linkages on the contrary show a significant difference between the only net oil and gas exporter (UK)[71] and the net oil and gas importers (China and Japan).

Country	Year	Linkages of oil & gas extraction with petroleum refining	
		Direct Backward	Direct Forward
UK	1995	0.4	0.28
Japan	2000	0.4	0.76
China	1997	0.48	0.78

Table (8): Direct backward and forward linkages of the oil and gas extraction and petroleum refining sectors with each other.

However, with this methodology being demand driven, only backward linkages are accounted for. Thus if the petroleum refining sector has its output reduced it will have less demand for inputs from other sectors – the crude oil and extraction sector being the one most affected. Hence there will be larger effects on the crude oil and extraction sector than just those caused by its imposed 10% output reduction. This effect can however not be reflected via a reduction of its own output (as this is exogenous) but will result in reductions of output in other non-supply constrained sectors and most of all in reduced final demand. If demand of households, investment and governments are assumed to remain constant, then this will be expressed in a reduction of net exports (i.e.: reduced exports or increased imports). Had it been a supply driven mixed model used here, only the forward linkages would have been considered, with the overlap of reductions shifting to the petroleum refining sector. Either way, some effects will be neglected. Given that both causational directions are important, Oosterhaven (1981) strongly advocates an approach which attempts to capture backward and forward links. Nevertheless each approach will require some level of abstraction from reality and making

[71] Unfortunately a more recent IO table fort the UK was not available. Such a table would show that the United Kingdom is increasingly becoming a net oil and gas importer too, as its production is in rapid decline (Campbell 2006b)

models overly complicated, may solely strain available data and research time, without contributing much to the accuracy of results.

1.3.3.2 Data

Three countries have been studied: the United Kingdom, Japan and Chile. With the exception of the UK (see Chapter 1.3.3.4.1), these countries have been chosen, due to availability of IO tables with suitable disaggregation. Looking for possible country candidates, the first problem encountered was that the aggregation level of most available country tables (e.g. those provided by the OECD) did not allow isolating the ”two oil sectors”[72]. Crude oil extraction always comes together with natural gas extraction and both are often part of “Mining and Quarrying”. Furthermore “Petroleum Refining” is contained in “Coke, Refined Petroleum Products and Nuclear Fuels” in many tables. This is consistent with the aggregation levels given by sector 23 of ISIC REV 3-1, the international industry classification system. The draft for ISIC Rev. 4 partially improves this situation, by not including nuclear fuels, but coking is still part of the new sector 19. NACE (revision 1.1), the classification code used by EUROSTAT (the European Unions’ Statistical Office), follows a similar pattern. For this reason even excellent and highly disaggregated tables such as the 261-sector Danish table for 1995 or the recent 84-sector German table for 2002, are characterised by this unfavourable sector combination. So far no European table could be located that would show petroleum refining as a single sector.

The same is true with regards to crude oil extraction for all tables which have been scanned, as it is always combined with gas extraction. Nevertheless this is not seen as a serious limitation, given that the two products, oil and gas, are highly interrelated throughout their lifecycle and for many uses can be regarded as substitutes for each other. In addition Peak Oil advocates predict world gas production to reach its maximum shortly after crude oil (Campbell 2006a; Mason IN PRESS). For future tests of this methodology it may even be beneficial to include a gas processing sector into the analysis as well, although it must be said that such sectors are usually combined with the actual physical supply, which would cause further distortions. In any case, the level of aggregation has to be kept in mind when analysing the results. Such it is to be expected that important known gas consumers, like electricity

[72] In order to avoid repetition of the full names of the “crude oil and gas extraction” and “petroleum refining” sector, these shall be referred to as the “two oil sectors” in this text.

production are bound to be more affected by the gas component of the constrained extractions sector than of the crude oil component.

Another criteria for choosing suitable country candidates, apart from finding suitable tables, was the intention to choose countries that would differ in terms of their development, geographical position and in terms of their own endowment of oil and gas resources i.e. of them being either net-oil exporters or importers. IO tables, if at all, are usually only generated in cycles of somewhere between every second to every 10th year. Hence it is very difficult to find tables of the same year when comparing countries. For this study a 1995, commodity-by-commodity, 138-sector, UK table; a 2000, commodity-by-commodity, 104-sector Japanese table and a 1996, commodity-by-commodity, 73-sector Chilean table were used. With the procedure outlined in Chapter 1.3.3.3.2 unterhalb, the disaggregation level was then reduced to 39, 43 and 40 sectors for the UK, Japan and Chile respectively. These particular levels resulted from singling out the sectors that were intuitively expected to be most affected, as will be described unterhalb.

1.3.3.3 Methodology

This methodology section will only discuss issues not covered already in the previous Chapters.

1.3.3.3.1 Technology assumptions and the problem of secondary production

One of the assumptions that have to be made when constructing square IO tables is that there is no secondary production. In other words every industry only produces one product. This primary product usually determines the respective industry classification. In reality of course this is rather the exception than the rule and most industries will also produce products which are typical for other industries. A travel agent may for example not only sell package holidays, but also act as a tour operator, own hotels, run its own fleet of buses and airplanes, etc. However if the company's main business is selling package holidays, its entire output may be assigned to retail trade and not to, for example, land-, air transport and hotels and restaurants. This would of course, be able to cause distortions in the representation of the economy in the resulting IO table.

In order to address this problem one firstly has to decide between one of two hypotheses regarding the technology of production. The first one being the "commodity technology" hypothesis, which assumes that there is only one way to produce a certain commodity, irrespective by which industry it is provided. The second one being the "industry technology" hypothesis, which is based on the idea that each industry has its own specific way of production, irrespective of the product mix. In this study only commodity-by-commodity tables based on the "industry technology" assumptions were used. These tables are derived from make and use matrices, in a procedure outlined in Miller and Blair (1985). Rows of the use matrix show the commodities produced by each sector and the columns show the industry sources of production. The make matrix on the other hand records the commodity inputs to an industrial process (Miller and Blair 1985). For more detail on this issue please consult Miller and Blair (1985 p. 159ff). Only the Chilean table had to be derived from the use and make matrices in this study, the others where readily available.[73]

1.3.3.3.2 Aggregation of sectors

As a result of the specific requirements for this study, large tables had to be used, which would be too bulky to work with and most of their detail would not be required for or even hinder the interpretation of the results. Thus each table was subjected to a custom aggregation process, taking advantage of the respective level of disaggregation. Sectors were scanned for possible obvious "losers" from the supply restrictions, which were to be left non-aggregated. These were firstly sectors which rely on oil as a direct input e.g. production of chemicals, plastics and transportation services and sectors depending on their products or services e.g. agriculture (pesticides, fertilizers, etc) and retail trading. Secondly these were sectors known to consume large amounts of energy e.g. cement production and iron smelting and all of those industries depending on their products and services e.g. construction and metal products. This strategy proofed to be successful since, with a few interesting exceptions, the largest changes happened in these sectors.

A simple procedure, outlined by Miller and Blair (1985, p. 174), was used for this aggregation. An aggregation matrix **S** of dimension (k x n) had to be built, where k is the number after aggregation and n the original number of sectors. Ones are to be placed wherever a sector was to be included in an aggregated sector, and zeroes everywhere else. Thus the row number of each cell would indicate the new sector after aggregation and the column number would provide the initial sector.

[73] All the tables used for this application and the intemediate results were to large to include in an appendix and are available as separate documents from the author.

Say one would want to aggregate a 4x4 matrix composed of Crop Production, Fisheries, Manufacturing and Services to a 3x3 matrix of Agriculture, Manufacturing and Services. The corresponding **S** matrix would be given as in Table (9) unterhalb. Additionally in order to be able to partition the matrix into supply-constrained and non-supply constrained sectors, the two oil sectors had to be transferred from their original place to position one and two of the aggregated matrix. This transfer can also be achieved with the **S** matrix. The new order simply has to be introduced in the naming of the rows and the ones and zeros shifted accordingly. Taking the same example as before, Table (10) shows how the original S matrix has to be transformed if Manufacturing was to change position with Agriculture. In continuation, matrices **Z**, **Y**, and **W** can be transformed to the new level of aggregation by means of multiplication with the **S** matrix and/or its transpose **S'** as shown in Eqs. (103),(104) and (105) respectively.

	Crop Production	Fisheries	Manufacturing	Services
Agriculture	1	1	0	0
Manufacturing	0	0	1	0
Services	0	0	0	1

Table (9): Example of S matrix for aggregation of a (4x4) matrix to a (3x3) matrix

	Crop Production	Fisheries	Manufacturing	Services
Manufacturing	0	0	1	0
Agriculture	1	1	0	0
Services	0	0	0	1

Table (10): The S matrix for reordering sectors

(103) $$\mathbf{Z^* = SZS'}$$

(104) $$\mathbf{Y^* = SY}$$

(105) $$\mathbf{W^* = WS'}$$

1.3.3.4 Results and interpretation

Table (11) unterhalb summarizes the findings after applying the supply constrained model with a 10% reduction of output in the oil sectors, to the three tables. It provides a full account of the reductions of output in all sectors in absolute (in the respective currency) and relative terms compared to their original outputs for the 1995-UK, 2000-Japan and 1996-Chile economies. Relative effects are shown because they will be most important for the sector itself in terms of detrimental implications for its continuing profitable operation. Absolute effects on the other hand may be significant for the whole economy, as GNP will be reduced. A large percentage decrease of output in a sector that is contributing little to GNP may be less harmful for the whole economy than a small percentage of an "important" sector such as wholesale & retail trade.

Generally it can be said that for all three countries the reduction of endogenous output caused in the **non-supply constrained sectors** by the reduction of available oil is rather minor in value terms, both absolute and relative. Relative to the total output of all non-supply constrained sectors prior to the 10% decrease of supply these reductions are 3.72, 0.96 and 1.48 per cent for the UK, Japan and Chile respectively (see bottom of Table (11). Since adding up the total of outputs results in some significant amount of double counting, the total changes are also provided relative to total value added (excluding the oil sectors) at the bottom of Table (11). However the proportions of changes remain roughly the same as when calculated in relation to total output with the UK showing 0.17%, Japan 0.028% and Chile 0.056% (see Chapter 1.3.3.4.1 unterhalb for a more detailed analysis).

Endogenous final demand of the **supply-constrained sectors** on the other hand shows rather dramatic relative changes in terms of their original value. The combined decrease amounts to 33, 768 and 418 per cent for each of the studied countries respectively [compare Table (12)]. However relative to GNP (i.e. total final demand) these numbers appear yet again rather minor with 0.3, 0.26 and 0.24 percent respectively (see Chapter 1.3.3.4.2 unterhalb for a more details).

The small relative changes encountered in both, the supply constrained and non-constrained sectors, seem little surprising however, given the fact that natural resource prices relative to GNP have been constantly decreasing in western economies over the years (Daly 2001). This fact has contributed to the development of the dematerialisation hypothesis[74], a concept which is related to the Environmental Kuznets curve[75] (e.g.: Selden and Song 1994; and for a critical review: Seidl and Tisdell 1999; Stern 2001). Various studies have shown that, in physical terms, only dematerialisation relative to GDP can be proven for some countries (Austria: Krausmann, Haberl et al. 2004). In most cases there is no absolute and often not even relative dematerialisation (Dittrich, Giljum et al. 2012).

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[74] Economies supposedly become more service oriented as they mature, thereby using less natural resources.

[75] The relation between economic growth and environmental pressure supposedly follows a hump-shaped curve i.e.: more growth results at a certain point in a decrease of pollution.

In terms of oil consumption measured in physical units, there can certainly be no talk of absolute dematerialisation, as the statistics provided in Chapter 2.2 (Part 1). In Figure 11 above it is further evident that both, real and nominal oil prices have been virtually unchanged for almost a hundred years from the 1870ies to the 1970ies, while GDP has been rising for most western countries (with the exception of periods of war). In fact real oil prices have even been on a steady decline for about 3 decades from the mid 1950ies to the early 1970ies. Of course, after the turmoil caused by the two oil shocks, there was an adjustment to reflect increased demand and the newly perceived scarcity and prices roughly doubled.

1.3.3.4.1 Non-supply constrained sectors

For the reasons stated above it is not so much the magnitude of change itself that is of interest, but to see which sectors are hit more than others when facing a supply restriction of a key resource. The entries in Table (11) have therefore been colour coded, to show the most affected sectors. Red/Orange/Yellow tones have been used for relative and Blue/Turquoise tones for absolute changes. The darker the colour, the more affected the sector. White cells remain for sectors with hardly any or no effects. Identical sectors have been combined for all countries in one row of Table (11) where possible as for example for coal extraction. However different levels of aggregation and different industry classification systems used by the British, Japanese or Chilean statistical authorities, made it often necessary to have one sector of one or two countries per row only. Cells with no entries have therefore no meaning. Table (12) further below contains the same data as Table (11), except that it reproduces the 10 most affected sectors in relative and absolute terms for each country, ordered from the most to the least affected. Colour codes are the same for relative changes, which are carried over to the column of absolute changes to facilitate the location of sectors affected both relative and absolute.

Sectors where combination was possible and where there were significant[76] effects in more than one country, either absolute or relative, are highlighted in green. The only sector which shows significant impacts in all three countries both absolute and relative is electricity production. This is most likely due to its reliance on gas as one of its mayor direct intermediate inputs in most countries. With electricity being a basic input for many other industries, this will be the cause of considerable indirect effects throughout the economies. In

[76] The term "significant" is used for the most affected sectors within a country.

Japan it is the sector with the third largest decrease in output, while it is on position seven in the UK and ten in Chile in relative terms [compare Table (12)]. In the case of the UK and Chile this clearly reflects the fact that the former generates 37% of its electric power from gas (148637 GWh) closely followed by coal with 35% (140312 GWh), while the latter produces 46% (22603 GWh) of its 48780 GWh total electricity output with hydro power and only 35% (17261 GWh) with gas (IEA 2006). In the case of Japan the results are less clear as its primary sources of energy for electricity production seem pretty diversified (28% coal, 13% oil, 24% gas, 23% nuclear, 10% hydro)[77].

[77] This data is for the year 2003, retrieved from www.iea.org. It is assumed here that the fundamental structure of energy production has not changed significantly since 1995 (UK), 1996 (Chile) and 2000 (Japan).

All Sectors	UK 1995 Absolute Δ mill. £	UK 1995 Δ%	Japan 2000 Absolute Δ mill. ¥	Japan 2000 Δ%	Chile 1996 Abs'lt Δ mill. Pts	Chile 1996 Δ%
Crude petroleum and natural gas [7][78]	1,743.35	-10.00	720,985	-10.00	6,410	-10.00
Refined petroleum products [33]	1,207.69	-10.00	1,366,010	-10.00	82,655	-10.00
Agriculture, Animals, Forestry (Fishing)	5.26	-0.02	563	-0.003	169	-0.007
Fish and other fishing products					29	-0.006
Coal extraction/mining	5.57	-0.23	362	-0.055	10	-0.045
Metal and Non-metallic ores [6-7]			-1,568	0.072		
Metal ores extraction [6]	0.01	-0.07				
Iron extraction [8]					9	-0.011
Copper extraction[9]					42	-0.001
Other minerals [10]					218	-0.033
Other mining and quarrying [7]	1.33	-0.05				
Foods [10-11]			1,256	-0.003		
Foods and Tabaco [11-21]					302	-0.007
Beverages [21-24]					32	-0.005
Misc. manufactured products (1/3) Japan [14-20]			4,161	-0.011		
Misc. Manufactured Prod. (1/2) Chile [26-32]					1,034	-0.032
Industrial gases and dyes [36]	1.32	-0.07				
Inorganic chemicals [37]	13.10	-0.99				
Basic inorganic chemical products [22]			332	-0.015		
Chemical fertilizer [UK 39] [Japan 21]	0.27	-0.03	49	-0.011		
Pesticides [41]	0.28	-0.02				
Organic chemicals [UK38] [Japan 23&24]	0.23	-0.01	1747	-0.023		
Plastics & Synthetic resins etc [40]	1.77	-0.03				
Synthetic resins & fibers [25-26]			318	-0.008		
Medicaments & Final chem. prod., n.e.c. [27-28]			2557	-0.017		
Basic chemical products [34]					248	-0.083
Other Chemical products [UK 42-45][Chile 35]	6.91	-0.03			343	-0.045
Coal products [30]			221	-0.019		
Man-made fibres [46]	0.09	-0.01				
Rubber Products [UK 47] [Japan 32] [Chile 36]	0.96	-0.03	194	-0.006	106	-0.077
Plastic Products [UK 48] [Japan 31] [Chile 37]	9.99	-0.07	1,280	-0.012	101	-0.027
Misc. manufactured products (2/3) Japan [33-34]			116	-0.004		
Misc. Manuf. products (3/3) Japan [36-37 & 62-63]			436	-0.003		
Glass and non metallic mineral products [38&39]					353	-0.056
Cement and cement products [35]			158	-0.004		
Iron & Steel Production [UK 54, J 39-41, Ch 40]	15.36	-0.14	980	-0.006	138	-0.044
Manuf.Non-ferrous metals [UK 55; J. 42-43; Ch 41]]	4.51	-0.08	355	-0.004	38	-0.023
Metal products [J.44-45, Ch. 42]			1,795	-0.013	628	-0.094
Manufacture -Metal casings [56]	1.31	-0.07				
Manufacture - Fabricated Metal Prod. [57-61]	89.29	-0.39				
Manufacture - Machinery & Applicances [62-70]	25.48	-0.06				
Electric& Non-eclectric machinery& equmnt [43&44]					374	-0.084
General machinery [46-49]			412	-0.001		
Electrical machinery [50-57]			483	-0.001		
Manufactoring (other) UK [8-34 ; 71-84 & 49-53]	67.50	-0.03				
Transport equipment [45]					146	-0.042
Cars, Ships and repair of ships [58-60]			966	-0.002		

[78] Numbers in square brackets next to the industry classifications stem from the sector-numbering of the original table and indicate the aggregation level.

Other transportation equipment & repair [61]			117	-0.003		
Misc. Manufactured Prod.(2/2)					109	-0.034
Reuse and recycling [64]			655	-0.038		
Electricity prod. & Distrib. [UK 85; J.69. Ch. 48]	35.38	-0.14	12,276	-0.073	693	-0.050
Gas, heat and water supply [69-71]			1599	-0.023		
Gas and Water Supply [86-87]	8.90	-0.07				
Gas [49]					5	-0.020
Water [50]					35	-0.017
Construction [UK 88, J. 65-68, Ch. 51]	147.21	-0.17	2916	-0.004	276	-0.005
Waste management service [72]			309	-0.009		
Wholesale and Retail Trade [89-92]	71.42	-0.04				
Commerce [73]			12,610	-0.013		
Trade services [52]					1,689	-0.028
Hotel & Restaurant Services [53&54]					355	-0.034
Railway transport [UK 93, J. 78, Ch.5]]	16.58	-0.20	1149	-0.017	54	-0.076
Other land transport [94]	22.05	-0.08				
Road transport (except by private cars) [79]			4079	-0.025		
Self-transport by private cars [80]			1523	-0.016		
Other road passenger transport services [56]					224	-0.025
Road freigth transport services [57]					2,927	-0.251
Water/Sea transport [UK 95; J. 81; Ch. 58]	2.82	-0.06	17,518	-0.328	14	-0.003
Air Transport [UK 96; J. 82; Ch. 59]	13.02	-0.13	601	-0.015	209	-0.055
Ancillary Transprt, Postal Services, Telecom [97-99]	54.43	-0.10				
Transport services, Freight fwding, storage [83-85]			12280	-0.140		
Services related to transport [60]					188	-0.028
Financial intermediation [100-114]	425.93	-0.15				
Financial and Insurance [J. 74, Ch. 62-63]			19,813	-0.051	430	-0.021
Real Estate, Business Services & Housing [64& 66]					4,048	-0.060
Real Estate Services and Rent [74-77]			3725	-0.006		
Communication and broadcasting [86-87]			4319	-0.019		
Communication services [61]					210	-0.021
Public admin., Educ. & Health Services [67,68,& 70]					7	-0.000
Public administration [UK 115; J. 88]	3.41	-0.09	115	-0.000		
Private Education & Health Services [69&71]					7	-0.000
Educ., health & social work [UK 116-118; J. 89-94]	9.98	-0.02	6,565	-0.008		
Other services [UK 119-123]	17.82	-0.04				
Other Services, Office Supplies etc. [95-104]			23,595	-0.016		
Other services [72&73]					343	-0.032
Total:	1079.51	-3.72	142,935	-0.96	16,145	-1.48
Relative to Total Value Added (excl. oil sectors)	647,101.48	0.167	514,403,135	0.028	28,779,675	0.056

Key:

most affected within country – Relative Change:	no/minor				largest
– Absolute Changes	no/minor				largest
Sectors affected in all countries (relative)					
Sectors of two countries affected (relative)			Positive Changes:		
Sectors of more than one country affected (absolute or relative)					

Table (11):Summary of empirical results for sector changes after applying a demand driven mixed IO model, with a 10% supply reduction of the oil sectors, to the UK, Japan and Chile (See text for detailed description)

Railway transport is also shows considerable effects in all three countries, although only in relative terms.[79] In absolute terms it does not even feature among the top ten for any country [compare Table (12)]. In relative terms it is the UK´s most affected mode of transport and in Chile it is only overtaken by Road freight. From the direct intermediate inputs it is not quite clear why this sector shows this reaction (in value terms most direct intermediate inputs come from "Ancillary Transports, Postal Services, Telecom" and "Financial intermediation"). These findings are particularly puzzling given the fact that rail transport is often regarded as the most energy and resource efficient mode of transport. Finally it should be noted that, three very similar sectors namely Wholesale and Retail Trade (UK), Commerce (Japan) and Trade services (Chile), all feature among the top four affected sectors in absolute terms, as one would expect given their importance in modern economies. Although considering this sectors reliance on transport, one would possibly expect even higher positioning, in particular in relative terms.

Sectors significantly affected in two countries are "Iron & Steel Production" (relative and absolute in the UK and relatively in Chile) and "Finance and Insurance" (relatively and absolute in Japan and absolute in Chile). However results in terms of sectors that may depend on coke such as iron smelting have to be interpreted with caution for the UK, due to the unfavourable aggregation level of one of the supply constrained sectors (see explanation below). Otherwise it is not surprising that this sector is affected given its energy intensity. Somewhat unexpected are results for "Finance and Insurance". In Japan, where it is the fifth most affected sector (in relative terms), its direct intermediate inputs come mostly from "Other services and Office Supplies", from itself, "communication and broadcasting", "Miscellaneous manufactured products (1/3)" and "Real Estate Services and Rent" (in that order), none of which show significant reactions. It must be the sum of indirect effects throughout the economy that shows an impact here. The UK's Finance and Insurance industry would probably join the Japanes and Chilean one, in terms of effects; it is however contained in the highly aggregated sector of "Financial Intermediation". This sector is the most affected in absolute and the 6th most affected in relative terms in the UK.

Intuitively most Peak Oil advocates argue that the "backbones" of an economy, namely Agriculture, Transport and Construction will be the sectors most impacted upon by supply restrictions of oil and gas. As far as transport is concerned, this can be confirmed for most

[79] For Japan it is not in the top ten, but comes with 0.017% shortly after number ten with 0.019%.

modes of transports by the results obtained here. Road Freight Transport in Chile is by far[80] the most affected sector in relative terms and comes second in absolute terms. Water Transport in Japan is equally the most affected sector in relative terms and comes third in absolute terms. In addition the important impacts caused to Rail Transport, in all three counties have already been mentioned above. The picture is different for Agriculture however. Despite its dependence on artificial fertilizers and pesticides, both of which require oil and gas for production, there are very small effects.

Even in Chile, where intensive industrial Agriculture and Fisheries are an important part of the economy, in particular with regards to exports, their combined changes (0.013%) are among the lowest. This surprising result can be partially explained with the equally surprising finding that, for those counties where fertilizer and pesticide production are available (UK and Japan), they also show very little impact. To some extent this can be attributed to the fact that for example in the UK both sectors depend much more on direct intermediate inputs from "Financial Intermediation" and "Wholesale and Retail Trade", than from Oil, Gas or Chemical production. Finally, as far as Construction is concerned, only in the UK this sector seems to be seriously impacted upon. The large requirements of energy intensive inputs such as metal and cement in this sector do not seem to make it a seriously affected victim of oil and gas supply disruptions in Chile and Japan.

[80] As it can be seen inTable (12) Road freight shows a reduction of output of 0.25%, while the figure for the next most affected sector (Metal Products) is only 0.09%.

UK 1995

relative sector change	%	absolute sector change	Mill £
Inorganic chemicals	-0.99	Financial intermediation	425.93
Manufacture - Fabricated Metal Prod.	-0.39	Construction	147.21
Coal extraction	-0.23	Manufacture - Fabricated Metal Prod.	89.29
Railway transport	-0.20	Wholesale and Retail Trade	71.42
Construction	-0.17	Manufactoring (other)	67.50
Financial intermediation	-0.15	Ancilliary Transprt, Postal Services, Telecom	54.43
Electricity production & Distribution	-0.14	Electricity production & Distribution	35.38
Manufacture -Iron and Steel	-0.14	Manufacture - Machinery & Applicances	25.48
Air Transport	-0.13	Other land transport	22.05
Ancilliary Transprt, Postal Services, Telecom	-0.10	Other services	17.82

Japan 2000

relative sector change	%	absolute sector change	Mill ¥
Water transport	-0.328	Other Services, Office Supplies etc.	23,594.84
Transportation services	-0.140	Financial and Insurance	19,813.29
Electricity	-0.073	Water transport	17,518.26
Coal mining	-0.055	Commerce	12,610.22
Financial and Insurance	-0.051	Transportation services	12,279.94
Reuse and redycling	-0.038	Electricity	12,275.62
Road transport (except by private cars)	-0.025	Education, health and social work	6,565.02
Gas, heat and water supply	-0.023	Communication and broadcasting	4,319.07
Organic chemicals	-0.023	Misc. manufactured products (1/3)	4,161.23
Communication and broadcasting	-0.019	Road transport (except by private cars)	4,078.59

Chile 1996

relative sector change	%	absolute sector change	Mill. Ptas
Road freigth transport services	-0.2513	Real Estate, Business Services & Housing	4,047.63
Metal products	-0.0937	Road freigth transport services	2,926.93
Electric& Non-electric machinery& equmnt	-0.0843	Trade services	1,688.74
Basic chemical products	-0.0831	Misc. Manufactured Prod. (1/2)	1,033.60
Rubber products	-0.0771	Electricity	693.44
Railway transport services	-0.0763	Metal products	627.74
Real Estate, Business Services & Housing	-0.0601	Financial & Insurance services	429.51
Glass and non metallic mineral products	-0.0559	Electric& Non-eclectric machinery& equmnt	374.13
Air transport services	-0.0554	Hotel & Restaurant Services	355.30
Electricity	-0.0501	Glass and non metallic mineral products	353.15

Table (12): The ten most affected sectors for the UK, Japan and Chile; absolute and relative[81]

Note: Results for two more country-case studies (China and India) can be found in Appendix I of this Chapter. Patterns of impacts are quite similar.

1.3.3.4.1.1 Chile: direct vs. indirect effects

On of the main advantages of IO models, as already mentioned, is that they show not only the direct but also the indirect effects of exogenous changes such as increases in final demand of the product of one particular sector. Hence this analysis goes further than merely looking at

[81] The colour coding for relative changes is the same as the one used in Table (11). The colour codes are carried over to the absolute changes in order to show which sectors are affected on both dimensions.

the sectors that use most oil and gas (directly) and assuming that these will be most severely hit by supply restrictions of these resources. The above discussion has already revealed that the Finance and Insurance sector, clearly not a very energy intensive one in terms of direct use, shows significant impacts in Japan and Chile. To illustrate this point further, the pattern of consumption of petroleum and gas derivatives[82] by sector for the 1996 Chilean economy is reproduced in Figure 31 unterhalb and compared to the model results shown in Table (12). Although the sector classifications are somewhat different to the one of the 1996 Chilean IO Table, it does allow for some comparison.

Land transport for one, occupies with 46% by far the largest share of total consumption of petroleum and gas derivatives, followed by "various industries" with 16% and (all of) services with 13%. In terms of road transport the comparison with Table (12) looks very similar at first glance, as road transport is equally at the top of the list of the ten most affected sectors in relative terms. However by finding roughly the equivalent of "various industries" of Figure 31, by summing up the effects of the four sectors following road transportation[83], a different picture emerges. Together they easily outweigh road transport in terms of relative change. In terms of absolute change road transport is dwarfed by the aggregate service sector of "Real Estate, Business Services & Housing", which also features fairly high up in terms of relative changes (position 7).

[82] This data was taken from a table showing total secondary energy consumption in calories. This means that the energy loss in converting the primary energy source (here crude oil and gas), to the secondary energy source (Petroleum, Diesel, Kerosene, LPG etc.) is not taken account of. It is assumed here however that the proportions would not change significantly if one was to do so.

[83] i.e.: metal products, electric and non-electric machinery and equipment, basic chemical products and rubber products

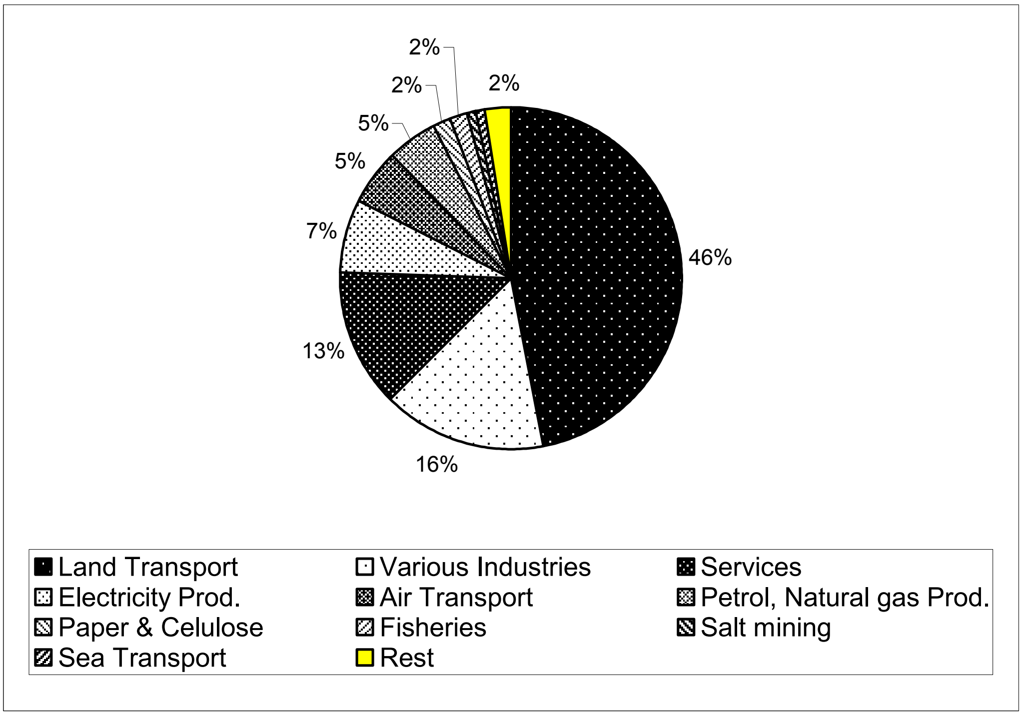

Figure 31: Use of Petroleum and Gas derivatives in the 1996 Chilean Economy[84]
Source: Graph - own calculation, Data – International Energy Agency (IEA)

Unfortunately the IEA data bundles all service sectors together, which makes it difficult to compare. Nevertheless given that only one service sector, "trade" is at position three in absolute terms, suggests that by merely using the direct use data would lead to a significant underestimation of the importance of the service sector in terms of reduced GNP during resource supply restrictions.[85] Sectors that follow in the order of direct use: Electricity Production, Air Transport, Petrol & Natural Gas Production, Paper and Cellulose, etc., all have different positions according to model results. Railway transport for example is more affected than air transport according to the model results, while in terms of direct use the latter is with 5% way ahead of the former with 0.15% of total consumption.

[84] „Rest" consists of: Gas, Coke, Natural Gas (0.55%), Copper (0.54%), Iron and Steel (0.37%), Iron ore mining (0.3%), Cement (0.18%), Rail Transport (0.15%), and Sugar (0.11%). The statistical data accessed here did not provide detail of the composition of "Various Industries".

[85] As a general note one may add here, that the service sector is probably the most flexible of all industries in terms of adaptation to resource scarcity. Although the sector today depends a lot on computer equipment which needs significant resources for production and which appears to have ever decreasing live spans; this equipment does not need a lot of energy. The sector is more likely to need more energy for heating and air conditioning then for running its computers. Thus in a shortage of oil and gas, the service industry may in the short run be able to switch to alternatives, such as using electricity for heating instead of oil, etc.

1.3.3.4.1.2 The United Kingdom

The model was also applied to a 138-sector commodity-by-commodity UK table for 1995, even though petroleum refining is bundled with coking and nuclear fuels therein. The rational being that the UK is of special interest, because together with Norway it is the only European net-oil exporter and one of the few western net-oil exporters in the world. Nevertheless it has to be mentioned that according to the Association for the Study of Peak Oil and Gas (ASPO) (Campbell 2006a), production of oil in the UK already peaked in 1999 and that of gas in 2003. The current oil production rate is believed to decline at 7.5% a year, meaning that it will be half of what it is today in about ten years. Today's oil production lies at about 1.8 Mb/d, while consumption already stands at 1.75 Mb/d (compare Figure 32) .Gas production is currently falling at 10% a year. In other words the picture has changed significantly since the time of the 1995 Table and the UK will soon become a net importer of Oil and Gas too.

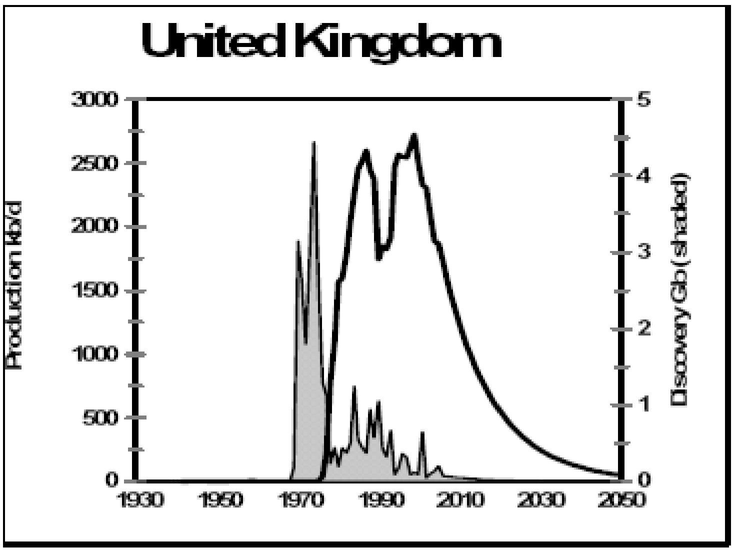

Figure 32: Oil production and discovery rates for the UK, current and predicted
Source: (Campbell 2006a)

In addition it was an ambition to have at least one European country within the analysis. As already mentioned above, the level of aggregation always has to be kept in mind, when results are interpreted. Reductions of output in sectors which are known to depend directly or indirectly on coke or nuclear fuels, such as iron smelting and electricity production respectively, therefore have to be interpreted with caution. To some extent, the fact that total relative reduction in output of the UK is about double of what it is in the two other countries, may also be attributable to the problem of aggregation. For future more rigorous analysis it will be necessary to find or construct an IO table which better fulfils the requirements of this study.

By far the most affected sector in the UK in relative terms is “Inorganic Chemicals”. This can somewhat be explained via the origins of its direct intermediate inputs, which all come from sectors that are more or less affected: “Financial intermediation”, Itself, “Wholesale and Retail Trade” “Other Land Transport”, “Electricity Production & Distribution”, “Gas and Water Supply”, etc (in that order). In addition a significant share comes directly from the restricted sector of “Coke Ovens, Refined Petroleum & Nuclear Fuel”. Significant reductions can also be observed, as already mentioned, in the Construction sector, both in relative (position 5) and absolute terms (position 2). Therewith it is the only country among the three studied, where Construction features in the top ten for relative and absolute effects.

1.3.3.4.1.3 Japan

There is little about the Japanese findings which has not already been pointed out above. Apart from its most affected sector, Water Transport, the most striking result is probably that “Metal and Non-Metallic Ores” actually increases its output by 0.07% after the oil sectors become restricted. This result can be traced back to the negative entry in the original inter-industry exchange matrix Z, which is due to the fact that in the Japanese tables by-products such as (in this case) scrap iron, resulting from joint-production with the main commodities, are treated as negative intermediate input. Inputs of the by-products on the other hand, are treated as positive intermediate deliveries (Kagawa 2006). Another particularity is the Japanese inclusion of the recycling sector in its 2000 table. This industry sees its output reduced significantly, making it the sixth most affected sector in Japan in relative terms. The related sector “Waste Management” on the contrary shows hardly any impact. Finally it might be worth noting that it is the only country were “Education, health and social work” (or a public service sector of a similar classification) shows some significant reduction in absolute terms (position seven).

1.3.3.4.2 Supply constrained sectors

As already mentioned at the beginning of Chapter 1.3.3.4, changes in endogenous final demand of the supply-constrained sectors have been considerable. Table (13) unterhalb summarises the respective changes of output and net exports for each country before and after the application of the model. It is not assumed here that imports of the two supply constrained sectors are restricted. Thus the reduction in total final demand can safely be interpreted as a reduction in exports or an increase in imports.

If imports were restricted, then the reduction in total final demand would have to be absorbed by all of the different final consumers, either according to their original share, or on the bases of some externally determined preferences. Thus one may for example argue that oil for heating homes should receive priority over government use of fuel for military purposes. In other words the government could impose some kind of rationing system. If this were not sufficient or not adequate, such a rationing system would have to look at reducing intermediate demand **Z**. According to certain criteria, some industries could again be given preference in receiving their share of oil and gas supply. Hubacek and Sun (2001) in their study with supply constraints on land, described above, have for example prioritized sectors according to their creation of value added per unit of land. This strategy favoured the labour intensive service sectors, which received their land share first. Combining linear programming with IO analysis could help to optimize the desired outcome, be it maximisation of output, value added, welfare, etc. If such a procedure were to be followed and imports maintained constant or even decreased, impacts on the whole economy would obviously be much more severe, as the shortfall of the restricted resource would be much higher.

		Total Final Demand (Y)				Net Exports (E^{net})		
		Y^{old} (before)	$Y_{new}^{-10\%}$(after)	$Y_{new} - Y_{old}$	%	before	after	%Δ
UK 95	crued oil & gas ex.	7,630	6,470	1,160	-15	6,200	5,040	-19
Mill. £	petroleum refining	6,640	5,480	1,170	-18	1,700	530	-69
Japan 00	crued oil & gas ex.	-23,500	-197,000	173,500	-738	-7,122,000	-7,295,500	2
Mill. ¥	petroleum refining	4,399,500	3,086,000	1,313,400	-30	-1,563,200	-2,876,600	84
Chile 96	crued oil & gas ex.	500	-1,300	1,800	-377	-536,700	-538,500	0
Mill. Pts	petroleum refining	201,400	119,400	82,000	-41	-294,500	-376,500	28

Table (13): Total final demand and net-exports before and after the supply shock[86]

Note: Results for two more country-case studies (China and India) can be found in Appendix I of this Chapter.

Another very tempting approach would be the compute a supply driven model. For net-oil importing countries it would be very easy to simply reduce the imports contained in the total outlays **W**. For net-oil exporters the oil sectors would have to be exogenised as shown by

[86] numbers are rounded

Giarratani (1976) and Chen (1986) in order to allow for them being restricted. However given the implausibility of the assumptions of this model, described at length above, its application may not be worthwhile. In any case for the moment we shall allow increases in imports.

The differences between the net oil exporter UK and the net oil importers Japan and Chile is clearly reflected in Table (13) oben. Relative reductions in final demands are much higher for Japan and Chile than they are for the UK. However the high percentage change of final demand for crude oil and gas of the net-oil-importers (738% Japan, 377% Chile), has to be seen in relation to the fact that for any country deliveries of unrefined oil and gas to final demand are very small. Due to some decreases in stock, Japanese total final demand of crude oil and gas is altogether negative - even before the supply shock. The only reason why deliveries are so high in the UK is because of exports. Instead of looking at the changes of final demand, it is more appropriate to analyse the difference between net-exports before (E^{net}_{old}) and after the supply restriction (E^{net}_{new}). For this purpose the absolute change in final demand ($Y_{new} - Y_{old}$), which is in fact the necessary decrease in net-exports or increase in net-imports after the supply restriction, has to be subtracted from E^{net}_{old} as shown in Eq. (106). Results of this computation for all three countries are provided on the right hand side of Table (13).

(106) $$E^{net}_{new} = E^{net}_{old} - (Y_{new} - Y_{old})$$

Negative figures in red letters for net exports on the right hand side of Table (13), can be seen as imports while positive figures are exports. The UK is still a net-exporter after the restriction, although its exports of crude oil and gas are reduced by about 20 and exports of refined petroleum by almost 70%. Such a reduction would possibly have a significant impact on world oil markets, as discussed in Chapter 2.2 (Part 1). The dramatic reductions of 738 and 377% of final demand for crude oil and gas in Japan and Chile immediately drop to a mere 2.44 and 0.34 % respectively, if seen as an increase of net-imports. In terms of refined oil products however it becomes evident that Japan will require almost a doubling of its imports and Chile an increase by nearly one third. These are very serious developments, which are bound to change the face of these economies.

1.3.3.5 Appendix I: Country case study results for China and India

China 1997

	relative sector change	%	absolute sector change	Mill. Yuan
1	Pipeline transport [93]	-4,747	Industrial Machinery & Equipment [62-66]	179.188
2	Water freight transport [94]	-0,564	Warehousing, Wholesale & retail trade [97 & 100]	168.775
3	Electricity production and supply [86]	-0,358	Electricity production and supply [86]	135.212
4	Maintenance & repair of machinery and equipment [82]	-0,351	Electric machinery and equipment [73-79]	134.431
5	Steam and hot water production and supply [87]	-0,346	Other chemical, medical & pharma products [42-45]	97.942
6	Coal mining and processing [6]	-0,305	Iron & Steel smelting and processing [55-57]	92.220
7	Other Transportation[96]	-0,294	Finance & Insurance	82.030
8	Raw chemical materials [38]	-0,280	Textiles, Wearing apparel & Leather [22-29]	78.690
9	Organic chemical products [41]	-0,267	Organic chemical products [41]	69.690
10	Railway freight transport [91]	-0,258	Coal mining and processing [6]	68.220
11	Water production and supply	-0,237	Miscalenious Manuf. Products (2/2) [80,81,83 & 84]	65.081
12	Finance & Insurance	-0,225	Public,Resident,Health, Educ.& Social services [114-118]	63.809

India 1998-99

	relative sector change	%	absolute sector change	Rs.Lakhs
1	Other chemicals [68]	-0,308	Banking & Insurance [109-110]	22.225
2	Banking & Insurance [109-110]	-0,179	Trade [107]	20.700
3	Electricity [100]	-0,178	Electricity [100]	19.726
4	Coal and Lignite [23]	-0,112	Other transport services [104]	11.664
5	Miscell. metal prod. & hand tools [76-77]	-0,097	Other chemicals [68]	7.504
6	Gas [101]	-0,091	Hotels, Restaurants & Other services [108&114]	6.584
7	Trade [107]	-0,078	Ind. machinery & tools (non-electric) [79-81 & 83]	4.238
8	Storage and warehousing [105]	-0,077	Miscell. metal prod. & hand tools [76-77]	3.659
9	Ind. machinery & tools (non-electric) [79-81 & 83]	-0,071	Construction [99]	3.420
10	Water supply [102]	-0,069	Agriculture, Animals, Forestry, Fishing [1-22]	3.419
11	Railway transport services [103]	-0,066	Coal and Lignite [23]	2.827

Table A1: The eleven to twelve most affected sectors for China and India; absolute and relative

		Final Demand (Y) of oil sectors				Net Exports		
		Y^{old}	Y^{new} -10%	Absolute Δ	%	before	after	%Δ
China 97	crued oil extraction	1.042.229	622.101	-420.128	-40	-69	-420.197	613.098,94
Mill. Yuan	gas ex.	323.282	220.148	-103.134	-32	0	-103.134	-96.605.232,25
	petroleum refining	991.455	-1.991.487	-2.982.943	-301	72	-2.982.870	-4.117.234,95
India 98/99	crued oil & gas ex.	-28.272	-92.884	-64.612	229	0	-64.612	-19.112.686,89
Rs. Lakhs	petroleum refining	1.708.545	1.154.551	-553.994	-32	28	-553.966	-1.990.528,14

Table A2: Total final demand and net-exports before and after the supply shock: China and India

1.4 The Price dimension of Peak-Oil within IO Analysis

1.4.1 The Price Model

Models discussed so far can be classified as quantity or volume models. Although this has not been done until now, they can be further divided into monetary and physical quantity models. Until know examples were mostly provided in terms of monetary volume models e.g. a_{ij} was defined as Euros worth of inputs from sector *i*, needed in sector *j* in order to produce one Euro worth of its output. Models of this kind are based on MIOTS (Monetary IO Tables). However inter-industry flows depicted in IO tables and models are ultimately exchanges of physical goods. In addition MIOTS cause problems in relation to the technical input coefficients. If the price of a product (output) changes, the assumption of fixed technical input coefficients translates this into the same change in inputs, which is not the case.

To take the example put forward by Miller & Blair (1985, p 351), a producer of steel may need 375 kw/h of electricity in order to produce a ton of steel. This amount of electricity input per ton of steel is not likely to change much if the price of electricity changed from, say, 2.0€ to 2.5€. In the former case this would imply $z_{electricity,steel}$ (deliveries from the electricity sector to the steel sector) of € 750, whereas in the latter case this number would be € 937.5. Thus the production function of the steel sector seems to have changed towards using more electricity per ton of output, although in reality the structural relationship is the same and only prices have changed. Effectively models based on MIOTS assume not only fixed physical technical coefficients (or engineering production function) but also fixed price ratios between inputs.

Thus it would seem more intuitive to record these transactions in physical rather than in monetary terms. Input-Output tables however are traditionally produced in a monetary form, i.e. they are usually MIOTS. Physical IO Tables (PIOTS) do exist for some countries but are still rare.[87] In those instances were data is available it is possible to develop physical quantity models, with similar properties to their monetary counterpart. Notwithstanding the use of PIOTS and the models based thereon is far from being a panacea to ecological economic modelling as it also raises difficult issues. This is for instance the case whenever a sector produces more than one product. Physically speaking, for example, a Mercedes and a Škoda are both one "unit of car", but their monetary values are very different.

Table (14) represents the basic IO relations in physical terms. Variables **h**, **f**, **g**, are merely the physical equivalents of **z**, **y** and **x**. The exogenously given payment sector is provided as the (*n*+1) sector. For this simplified example it is assumed that there is only one such payment sector, namely labour (measured in man hours). In other words **w** equals **l** instead of **l** plus **n** and **m**, according to the notation laid out in Table (3) above. Moreover this means that final physical demand (f) will only consist of household consumption. Thus the physical parallel of the basic IO accounting relationship of Eqs. (1), (2) and (3) are represented by (107) and (108). If prices p_i of physical units for all (*n*+1) sectors are known, it is possible to convert the individual physical entities **g**, **f** and **H** into their monetary equivalents **x**, **y** and **Z** via equations (109), (110) and (111) respectively. Hence Table (15), the monetary parallel of Table (14), can be found by multiplying all entries in row *i* by p_i. Table (15), is equivalent to Table (3) above.

Sectors	Sectors				Final demand	Total (Gross) Output
	1	2	…	n	(f)	(g)
1	h_{11}	h_{12}	…	h_{1n}	f_1	g_1
2	h_{21}	h_{22}	…	h_{2n}	f_2	g_2
⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	h_{n1}	h_{n2}	…	h_{nn}	f_n	g_n
n+1	$h_{n+1,1}$	$h_{n+1,2}$	…	$h_{n+1,n}$	f_{n+1}	g_{n+1}

Table (14): Physical IO flows

(107) $$g_i = h_{i1} + h_{i2} + \ldots + h_{in} + f_i = \sum_{i}^{n=1} h_{ij} + f_i$$

[87] Interest in environmental issues over the last few decades has also increased the interest in environmental satellite accounts, to complement the traditional monetary national accounts. The development of Physical IO Tables could be seen as a direct result of this trend. However, according to Hoekstra (2005) there are currently only PIOTS for five countries available: the Netherlands, Germany, Denmark, Italy and Finland.

(108) $\mathbf{g} = \mathbf{Hi} + \mathbf{f}$

(109) $x_i = p_i g_i$

(110) $y_i = p_i f_i$

(111) $z_{ij} = p_i s_{ij}$

Sectors	Sectors				Final demand	Total (Gross) Output
	1	2	…	n	(y)	(x
1	z_{11}	z_{12}	…	z_{1n}	y_1	x_1
2	z_{21}	z_{22}	…	z_{2n}	y_2	x_2
⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	z_{n1}	z_{n2}	…	z_{nn}	y_n	x_n
n+1	$z_{n+1,1}$	$z_{n+1,2}$	…	$z_{n+1,n}$	y_{n+1}	x_{n+1}

Table (15): Monetary IO flows

Note that physical tables are usually produced in one single unit of measurement; foremost in weight i.e. tons. Hence they do adhere to the fundamental IO accounting balance of row sums being equal to column sums, according to the mass-balance-principle. The variable g_j can therefore be obtained as usual by summing down the j^{th} column. Doing so allows calculating x_j as in Eq. (112), which is derived from Eq. (6) above. Moreover one can derive a technical coefficient [t] in physical terms as shown in Eq. (113). This coefficient would describe for example the labour hours per car or the kilowatt-hours of electricity per ton of aluminium.

(112) $$x_j = p_j g_j = \sum_{i=1}^{n} p_i h_{ij} + p_{n+1} h_{n+1,j}$$

(113) $$t_{ij} = \frac{h_{ij}}{g_j}$$

Provided that technical coefficients in value terms [a_{ij}] are found as in Eq. (12) and its physical counterpart t_{ij} as in Eq. (113) above, it can be shown that the price ratio between sector *i* and *j* relates these coefficients to each other [see Eq. (114)]. The basic demand driven IO assumption of fixed technical coefficients can be applied to both of them. Whereas in the case of a_{ij} this implies a fixed economic production function, for t_{ij} it could be regarded as the assumption of a fixed engineering production function. However equation (114) below illustrates that by assuming a fixed economic production function, one implicitly assumes not only a fixed engineering production function but also a fixed price ratio (p_i/p_j), as already mentioned above.

(114) $$a_{ij} = \frac{z_{ij}}{x_j} = \frac{p_i h_{ij}}{p_j g_j} = t_{ij}\left(\frac{p_i}{p_j}\right)$$

Having established the convertibility of monetary parameters into physical ones and vice versa, one can derive the mathematical duals of the physical and monetary quantity model. These are given by the respective (Leontief) price models. The goal of the Leontief price models is to determine the effect on prices in some given year due to a change in the exogenously determined value added per unit of physical output. Thus one could be interested to explore how prices throughout the economy would be influenced by a substantial pay rise in one sector. The intuitively more obvious price model, representing the mathematical dual of the physical quantity model, is derived as follows.

Equation (112) is firstly divided by g_j in Eq. (115), which will permit to calculate the price of sector *j*. If the expression for physical technical coefficients [Eq. (113)] is then incorporated into Eq. (115), one arrives at Eq. (116). To proceed the right hand side of Eq (116) (value added per unit of physical output) shall be denoted as d_j. In order to continue with further manipulations it is helpful to solve the newly created Eq. (117) for the two-by-two case as in (118). Rearranging the equations to have only d_j on one side results in a similar structure from which one can extract the matrix annotation of Eq. (120) to (121). Rearranging once more will allow to calculate the changes in prices [**p**] caused by some exogenously determined value added per unit of physical output [**d**]. The necessary physical coefficients are taken from the base period, which is allowed by the assumption of fixed engineering production functions mentioned above. Equation (122) finally represents the Leontief price model, which is the dual of the physical quantity model.

(115) $$p_j = \sum_{i=1}^{n} \frac{p_{ij} h_{ij}}{g_j} + \frac{p_{n+1} h_{n+1,j}}{g_j}$$

(116) $$p_j = \sum_{i=1}^{n} p_{ij} t_{ij} + p_{n+1} t_{n+1,j}$$

(117) $$p_j = \sum_{i=1}^{n} p_{ij} t_{ij} + d_j$$

(118) $$p_1 = p_1 t_{11} + p_2 t_{21} + d_1$$
$$p_2 = p_1 t_{12} + p_2 t_{22} + d_2$$

(119) $(1-t_{11})p_1 - t_{21}p_2 = d_1$
$-t_{12}p_1 + (1-t_{22})p_2 = d_2$

(120) $\mathbf{p} = \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$, $\mathbf{T'} = \begin{bmatrix} t_{11} & t_{21} \\ t_{12} & t_{22} \end{bmatrix}$, and $\mathbf{d} = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix}$;

(121) $(\mathbf{I}-\mathbf{T'})\mathbf{p} = \mathbf{d}$

(122) $\mathbf{p} = (\mathbf{I}-\mathbf{T'})^{-1}\mathbf{d}$

This model is based on ‘absolute prices’ e.g. the price of one ton of steel and on physical coefficients t_{ij}. Nevertheless, physical coefficients are usually difficult to obtain as secondary data. Thus it may be easier to employ the dual of the monetary quantity model (Figure 33 illustrates the relation between the two quantity models and their duals). As already mentioned in Chapter 1.2.2 above, a_{ij} indicates how many Euros worth of inputs from sector *i* are necessary in order to produce one Euro worth of total output in sector *j*. In other words the price of one unit of output is per definition one Euro, because a_{ij} is calculated on a “per-euros-worth of output” basis (Miller & Blair 1985). Hence these prices could be regarded as ‘normalized’ prices. Given a vector[88] of coefficients of value added per unit (euros worth) of output [**k**] and a vector of normalized prices [$\bar{\mathbf{p}}$] one can obtain the value-based counterpart of Eq. (122) as in Eq. (123) unterhalb. Initially $\bar{\mathbf{p}}$ will per definition be a vector of ones. After a change in the technical coefficients due to some exogenous change in k however, $\bar{\mathbf{p}}$ will be modified. These modified prices will represent relative price changes due to a change in production. Thus, if for instance the new p_1 equalled 1.07, this would indicate a 7% increase of prices in sector one due to the new production process.

(123) $\bar{\mathbf{p}} = (\mathbf{I}-\mathbf{A'})^{-1}\,\mathbf{k}$

[88] For simplicity, only one value added sector i.e. labour is assumed here. Otherwise the coefficients of value added per unit of output would be represented in matrix **K** rather than in vector **k**.

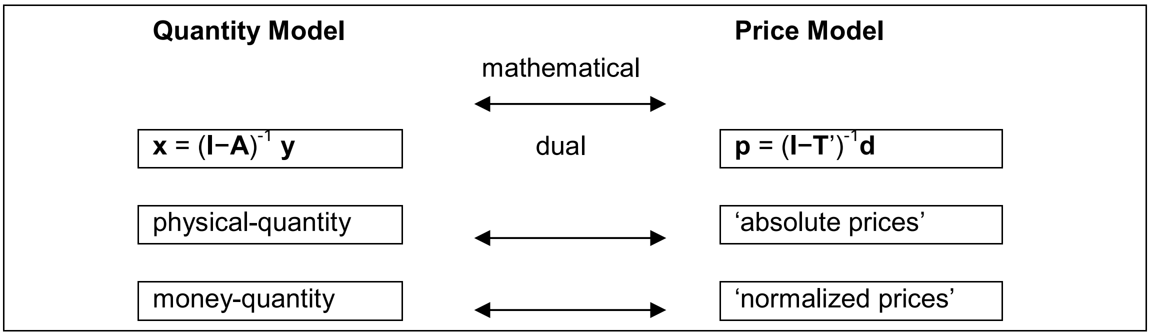

Figure 33: Mathematical Duality between Quantity and Price Models
Source: Adapted from Idenburg 1993, p. 20, Figure 2.3

1.4.1.1 Empirical applications of Price Models

The above price model is commonly used to assess the effects of an increase in value-added costs (e.g.: labour or capital) in one or more sectors upon product prices throughout the economy. Melvin (1979) for example used it to estimate the impacts of an increase in corporate income tax in the United States and Canada. Over time, a number of variations of the traditional Leontief price model have appeared - examples are Moses (1974), Polenske (1978) and Lee et al. (1977). Lee et al. (1977) exogenised four sectors, namely wheat, electricity, petroleum and natural gas production, to model the impacts of exogenous price changes in these sectors on the regional economy of the US state of Washington. The authors conclude that changes in price and changes in physical demand, differ in their economic impacts and even affect different segments of the economy (Lee, Blakeslee et al. 1977). One of their results, for example, shows that higher wheat prices produce higher income for the wheat sector and the state, but affects a few sectors negatively. Moreover, if final demand for wheat increases, all sectors benefit, however every one to a different extent.

More recent applications of the price model include most of all the works of Faye Duchin and Glenn-Marie Lange. In their joint 1992 Article "Technological choices and prices, and their implications for the US economy, 1963-2000" , they pioneer the application of a *dynamic input-output physical, price and income model*. This sophisticated model is made up of three interrelated submodels – a dynamic physical, a dynamic price and a dynamic income model. It was used to investigate the influence of technological change and change of factor prices in the US economy on prices and incomes between 1967 and 2000. The rational behind this study is that the cost savings from new technologies can either be captured by the factors of production i.e.: by the firm via higher profits or by the employees via wage increases, or can be passed on to consumers through reduced product prices. The input-output framework captures the knock-on effects throughout the economy if prices of some sectors are reduced. The same basic idea is also the subject of a later publications of the two authors (Duchin and Lange 1995a; 1995b).

For example, cost savings allowed by new extraction or refining technologies employed by the petroleum industry, could be passed on to consumers and generate effects throughout the economy. The same is true for price increases of course. If these price increases are a result of reasons other than increased production costs[89] i.e. by speculation or scarcity, then the mark-up has to be captured by somebody. In the case of oil this could be either through increased royalties charged by petroleum exporting countries or by increased profits of petroleum refiners and retailers.[90] Thus a similar model in a one-country framework could be constructed, where a certain percentage increase in royalties or profits of the petroleum industry is included in **d** or **k**. This procedure would even be possible employing a simple static price model. The study of Duchin and Lange (1992) already implicitly studies the impacts of the oil price increases during the 1970ies on the different economic sectors.

The big disadvantage of the price model is that, just as any demand side IO model, it takes final demand as given. Thus the price model will only show how prices **p** or $\overline{\mathbf{p}}$ would change throughout the economy due to an inflated price of a key resource. It would not show however how final demand **Y** would react**,** given the price rises. The supply constrained model on the other hand will at least indicate the reaction of final demand of the supply constrained sectors. Nevertheless given the fact that oil is a very price inelastic commodity, it could be argued that demand will, at least in the short run, not decrease significantly due to increased oil prices. Experience from the two oil shocks has shown that prices have to reach astronomical heights before demand for petroleum gives in. Hence it is more likely that authorities will opt for price controls and rationing systems like in the 70ies rather than leaving prices to rise freely. This would be a necessary step in order to prevent significant

[89] According to Peak Oil advocates the extraction of oil, as already mentioned above, will become more and more expensive with maturing oil wells. The better quality, easy to extract "sweet oil" is the one that runs out first. Afterwards for example CO_2 has to be injected to retrieve the remaining crude oil. Even more expensive is oil produced from the famous Canadian tar sands, which apparently hold more oil than there is in Saudi Arabia. It is however not only the monetary but also the environmental costs that increase with the exploitation of inferior sources of oil.

[90] Since the increases of oil prices in recent years have been accompanied by the most formidable increases in profits of oil companies, one could conclude that - at least for the moment – so far oil extraction costs are not fully responsible for high oil prices and that oil companies capture a major share of the increased mark-up.

damage or even a collapse of an economy. What follows from this defence of the price model is another disadvantage thereof. Because of the possibilities of large price surges and possible price controls, it is, in terms of developing scenarios for Peak Oil, somewhat easier to assume a certain quantitative reduction of available oil on world markets, than it is to derive an estimate of what prices may be.

For these reasons the price model will not be employed in this study. Notwithstanding it cannot be disputed that there is a price dimension to Peak Oil as well as there is a quantity dimension. By employing the supply constrained model, as it is done below, one assumes that prices remain fixed. In the absence of price controls this is a very restrictive assumption, given the volatility of world oil prices. Thus for future research it may be of interest to use a price model alongside a quantity model, to reflect both of these dimensions. Appendix I of this Chapter – reproduces some first results and observations form a first application of the Price Model (PM) to IO tables of the UK, Japan and China

1.4.2 Appendix I –Application of the PM to UK; Japanese and Chinese data - Results and Observations

Transport	Gas and Water Supply /production	Electricity Production /Distribution
Transport related	Steam / Hot Water	
Chemical products (organic)	Metal Ores	Plastics, Sythetic Resins
Chemical products (inorganic)	Non-metallic ores	Manmade Fibers
Fertilizers (chemical)	Other mining	Rubber

United Kingdom (UK)		Japan		China	
				Crude petroleum products	82,9
Oil and gas extraction	74,1	Curde petroleum and natural gas	99,6	Petroleum refining	75,7
Coke ovens, ref. petroleum & nuclear fuel	73,6	Petroleum refinery products	93,7	Natural gas products	61,0
Gas and Water Supply	21,5	Self-transport by private cars	29,5	Water passenger transport	19,9
Fertilisers	5,5	Organic chemicals	18,1	Water freight transport	19,4
Electricity production & Distribution	4,0	Reuse and recycling	14,7	Air freight transport	14,1
Organic chemicals	3,6	Electricity	11,7	Gas production and supply	11,8
Other land transport	3,2	Coal products	10,8	Highway freight transport	11,0
Air Transport	2,8	Gas, heat and water supply	10,5	Pipeline transport	10,3
Inorganic chemicals	2,6	Synthetic resins & fibers	9,5	Highway passenger transport	9,7
Water transport	2,0	Road transport (except by private cars)	7,2	Steam & hot water prod. & supply	9,1
Plastics & Synthetic resins etc	1,9	Chemical fertilizer	6,9	Organic chemical products	8,2
Metal ores extraction	1,8	Water transport	6,1	Air passenger transport	7,3
Manu.-Man-made fibres	1,7	Air transport	5,8	Electricity production and supply	7,2
Other mining and quarrying	1,5	Metal and Non-metallic ores	5,8	Chemical fertilizers	6,9
Manufacture -Iron and Steel	1,5	Basic inorganic chemical products	5,1	Railway freight transport	6,6
Industrial gases and dyes	1,3	Rubber products	4,3	Coking	6,4
Coal extraction	1,1	Plastics products	3,9	Railway passenger transport	5,8
Agriculture, Forestry,Fishing	1,0	Cement and cement products	3,8	Non-metal minerals and other mining	5,5
Wholesale and Retail Trade	0,9	Iron and Steel	3,4	Non-metalic mineral products	5,4
Railway transport	0,8	Medicaments & Final chem. prod., n.e.c.	2,8	Construction	4,7
Manuf. - Fabricated Metal Prod.	0,8	Non-ferrous metals	2,6	Iron & Steel smelting and processing	4,7
Manufacture -Metal casings	0,8	Agriculture, Forestry,Fishing	2,5	Oth. chemical, medical & pharma prod.	4,2
Manu.- Plastic Products	0,7	Misc. manufactured products (1/3)	2,5	Raw chemical materials	4,2
Manu.- Rubber Products	0,7	Construction	2,4	Chemical pesticides	4,1
Other Chemical products	0,7	Waste management service	2,2	Other Transportation	4,0
Manufacture -Non-ferrous metals	0,6	Misc. Manuf. products (3/3	2,0	Alloy iron smelting	3,6
Manufactoring (other)	0,6	Misc. manufactured products (1/3)	1,9	Cement and asbestos products	3,5
GG - Other services	0,6	Metal products	1,9	Ferrous and non-ferrous ore mining	3,5
Manufacture - Machinery & Applicances	0,5	Foods	1,7	Railroad transport equipment	3,3
Pesticides	0,5	Cars, Ships and repair of ships	1,7	Nonferrous metal smelting & processing	3,3
Ancilliary Transprt, Postal Services, Telecom	0,5	Public administration	1,4	Plastic products	3,3
Other services	0,4	General machinery	1,4	Public,Resident,Health, Educ.& Social services	3,3
Construction	0,4	Education, health and social work	1,4	Metal products	3,2
Financial intermed-iation	0,4	Railway transport	1,4	Water production and supply	2,793978337
Public adminis-tration	0,4	Commerce	1,4	Coal mining and processing	2,7
GG - Public administration	0,4	Other transportation equipment & repair]	1,3	Maintenance & repair of machinery and equipment	2,7
GG - Education, health and social work	0,4	Other Services, Office Supplies etc.	1,3	Rubber products	2,5
Education, health and social work	0,3	Electrical machinery	1,2	Cars, Ships and Aircraft	2,5
NPISHs	0,2	Transportation services	1,1	Warehousing, Wholesale & retail trade	2,4
		Communication and broadcasting	0,9	Industrial Machinery & Equipment	2,3
		Financial and Insurance	0,6	Electric machinery and equipment	2,2
		Real Estate Services and Rent	0,3	Miscalenious Manuf. Products (2/2)	2,2
		Coal mining	0,2	Bicycles & other transport machinery	2,2
				Other services & Public Admin.	2,2
				Logging & transport of timber & bamboo	2,2
				Miscalenious Manufactured Products (1/2)	2,1
				Agriculture,forestry,animals & fishing	1,9
				Post & Telecommunication	1,8
				Foods, Beverages & Tabacoo	1,7
				Textiles, Wearing apparel & Leather	1,5
				Finance & Insurance	1,2
				Real estate	1,0
				Scrap and waste	0,0

Table A1: Results of a price model application to the UK, Japan and China

Obersvations:

1) Transport sectors- extremely affected

1a) Railway transport - least effected

1b) Road transport - most affected (except for China)

1c) China: freight higher affected than passenger transport (except water)

2) Electricity - highly affected

3) Gas and Water Supply – highly affected

4) Chemicals - affected

5) Mined goods - affected

5a) Coal - least price increase of mined goods

6) Agriculture: little, despite fertilizer increase

6a) here of interest - disaggregation of agricultural sector - because forestry, fishery not dependent on fertilizers

Country differences:

1) UK - oil producer - prices less affected

1a) UK - oil sectors least affected

2a) Japan: Reuse & Recycling - will we no longer be able to afford recycling?

2b) Japan: Coal products vs. Coal mining

1.5 Other models

The list of approaches analysed in this study is by far not exhaustive and there will exist numerous combinations and variations. The most important ones, for purpose of this study, shall be presented in a nut shell below. They are the World Model, Linear programming and IO analysis and MRIO. An in depth analysis of these models is beyond the scope of this paper and shall be the subject of future studies.

Models that attempted to present the world economy first appeared in the 1970ies. Possibly the most widely known of these was the one developed by Donella and Dennis Meadows (1972). The first world model based on IO analysis was presented by Wassily Leontief, Anne Carter and Peter Petri (Leontief 1974; Leontief, Carter et al. 1977). The latter study attempted to evaluate ways of reducing the gap in material well being between rich and poor nations. Of particular interest for analysing supply constraints of important resources is the World Trade Model (WTM) developed and applied by Faye Duchin (2005), which generalizes the World

Model of Leontief, Carter and Petri. The goal of the first application of the model was to establish if world trade was of overall benefit to the world economy. The results showed that "*…the world as a whole benefits from trade because the same consumption vectors are satisfied as in the absence of trade, but with lower factor use*" (Duchin 2005, p.143.

The WTM is effectively a linear programming model of world trade with *m* regions, *n* goods and *k* factors of production. At the same time it's a single-region IO model that has been closed with respect to international trade. Endogenous variables are output, exports, imports, factor scarcity rents for each region, and world prices for traded goods. Their values a are determined through "*production assignments*" (Duchin 2005). These are made for every good according to the competitive advantage of the respective country. The model has been designed to test the effectiveness of actions to achieve the objectives associated with sustainable development. Scenarios of some radical deviations[91] from current practice could be implemented in the model and its effectiveness predicted. The linear programming part of the model is used to minimize factor usage rather than maximize consumption or economic growth, as it is common practice in orthodox approaches.

It seems that such a model could provide the ideal basis for extending the research presented in this study. A world model would address the two main weaknesses of the mixed model applied below, namely the assumption of fixed prices and its limitation to the national level. Moreover the model could not only be used to assess policies to minimize CO_2 emissions, as it is suggested by Duchin (2005), but could also provide a broad framework for analysing the impacts of Peak Oil scenarios and of policies to cope with the effects of such supply constraints. A precondition for this would of course be the widespread recognition of the phenomenon of Peak Oil and it's potentially far reaching implications for world economies. So far signs of the acknowledgement of the necessity to reduce resource consumption are only implicitly visible through the goals of the Kyoto Protocol. Otherwise the emphasis of policy makers still seems to be mostly placed on advancing technological innovations, for dealing with resource and energy scarcities (Luzzati and Franco 2005).

[91] Such radical deviations are defined by Duchin (2005) as those which are not marginal and motivated by considerations other than changes in prices and incomes. As an example she provides the replacement of a meat based with a plant-based diet to improve personal health and to reduce environmental pressures, rather than switching for example from butter to margarine consumption because of changes in incomes or relative prices (Duchin 2005)

An obvious challenge for any World Model is the availability of data, data reconciliation and computability. Multi-Region-Input-Output (MRIO) models could be regarded as the bridge from single-regional models to the World model. The MRIO approach involves not the entire world but takes one country and includes all of its mayor trading partners. Hence data requirements would still be significant, but less than in a World Model. Just like a World Model would do for the entire world economy, a MRIO model would be able to capture most of the oil flows [(compare Figure 30)] of one particular economy. Most importantly it would account for the embedded oil in imported products. Assessing the robustness off indicators for embedded emissions and impacts, a draft final report, compiled for DEFRA[92] by the Stockholm Environment Institute (SEI) and the Policy Studies Institute (PSI) (Wiedmann, Minx et al. 2006), shows that studies based on MRIO Models (e.g.: Lenzen, Pade et al. 2004; cited by: Wiedmann, Minx et al. 2006) score significantly higher than those based on Non-IO models (e.g.: Muradian, O'Connor et al. 2002), Single-Region IO models (e.g.: Sanchez-Choliz and Duarte 2004; cited by: Wiedmann, Minx et al. 2006) or those based on CGE models (e.g.: Lutz, Meyer et al. 2005). Nevertheless, as the report admits, constructing comprehensive MRIOS models is a non-trivial task, requiring significant amounts of data and research time.

1.6 The Basque Country's vulnerability to Peak Oil[93, 94]

We have enough reasons to believe that we are nearing or have already reached the world's maximum possible level of oil extraction: Peak Oil. This means that sooner or later the price of oil will rise again, inevitably leading to a renewed global crisis. Despite this significant risk posed by Peak-Oil, as for example illustrated by the historic examples of Peak-Oil like events in Cuba and North Korea in the 1990ies (Friedrichs 2010), there is, to our knowledge, no country in the world which has official contingency plans for such a case. Nevertheless, there are some local (Portland City Peak Oil Task Force 2007; Lundberg 2009) or national initiatives (Bailey, Hopkins et al. 2010), projects (Korowicz 2010; Schriefl, Fischer et al. 2011) and impact studies (Hirsch 2005; Czúcz, Gathman et al. 2010; USJFC 2010; Vanderschuren, Lane et al. 2010; ZTransfBw 2010; Kerschner 2012). These are important wake-up calls, as they bring the concept of Peak-Oil and its dangers closer to the people, who may engage in bottom-up adaptation and preparation processes.

[92] UK - Department for Environment Food and Rural Affairs

[93] This Chapter is the revised and updated English translation of Chapter 4 (p. 96-108) of (Arto-Oliazola and Kerschner 2009).

[94] Translation from Spanish to English: Iñaki Dominguez Gregorio and Christian Kerschner

In this study we derive a group of indicators for evaluating the vulnerability of the Basque country to Peak-Oil. Some of the Basque Economy's specific characteristics, such as its energy dependence, its energy and transport intensity, as well as the importance of road transport in its fabric or the close connection of certain sectors with products whose demand is especially sensitive to the price of oil, represent a serious threat in a scenario of energy shortage.

The transcendence and imminence of the challenge we assume, requires immediate action from Basque society as a whole. As well as developing a contingency plan, we have to undertake vulnerability analysis and find a strategy for the transition towards a post-carbon society.

In 2008 the Basque Government published a report analysing the potential effects of an increase in the price of oil on the Basque economy (Basque Government 2008). This report concluded that in a pessimistic scenario, with an oil price close to 205 dollars/barrel in 2015 at constant prices of 2006, the rise in the energy costs would involve a contraction of the Basque Country's GDP of only 1% and of 0.9% of employment.

This report analysed the effects of a loss of competitiveness due to the relative cost increase produced by the rise in the oil price. In our analysis we intend to go further by studying specific variables which we consider especially relevant in order to determine the degree of vulnerability, as: energy dependence, the total energy intensity of the different economic sectors and their transport intensity, or the links between the activity of certain sectors and products whose demand is especially sensitive to oil prices.

As we have mentioned above, oil plays an essential role in today's society. In the short run, oil is practically irreplaceable as a source of energy for the transportation of people and goods. It is for this reason that the demand of oil is highly rigid, so that the slightest scarcity results in large price increases. This happens until a point is reached, a threshold, when high oil prices begin to destroy demand. This has been the case throughout historic oil crises, including the one in 2009. Eventually, so it is argued (Hamilton 2009; Our Energy Future 2010) (Murphy and Balogh 2009; Theramus 2009; Lewis 2010; Chanel 2012) this causes a contraction of GDP in most countries. In general, it has been estimated that a reduction of one point in oil supply, can result in a similar reduction of GDP (Hirsch 2008).

In a scenario such as the one described above: with energy scarcity in the short and medium run; a further increase of oil demand with respect to present levels and in the absence of any measures that would mitigate this process[95] - we will face further increases in oil prices.

As it has already happened in the past, those developing countries which are oil importers will be the first to suffer the consequences of such an increase. Rich countries on the other hand will have more time until their economies start to be seriously impacted by high petroleum prices. In general, the severity of these impacts will depend on the energy dependence and intensity of each individual country.

The Basque Country shows relatively high energy dependence. In 2007 its Primary Energy Production (PEP) reached 420 kilotons of oil equivalent (ktoe). This number covers only 5% of Gross Domestic Energy Consumption (GDEC), thus the remaining 95% of energy needed to sustain the Basque economy must be imported from other regions (see Table (16)). This ratio is 79% for all of Spain and 53% for EU-27 Petroleum products represent the Basque Country's main energy source (41% of the GDEC), closely followed by natural gas (39%) (see Table (16)). Altogether, fossil fuels represent 86% of GDEC. However in order to get a reliable picture of their true weight in GDEC one needs to add fossil fuels associated with the imports of electricity. In that case they would represent 89% of GDEC.

[95] We have already outlined the difficulty of introducing measures oriented to face an energy crisis in the short or medium term.

	PEP *(a)*	GDEC *(b)*	GDEC Fossils	GDEC Rebls	Energy depend.	Population	GDEC	GDP	Energy Intensity *(c)*
	ktoe	ktoe	%	%	%	miles	toe/cap	10^9 €s	Ktoe./€
Germany	135.263	339.568	81%	8%	60%	82.266	4.13	2.423	0.14
Austria	10.431	33.809	73%	24%	69%	8.315	4.07	271	0.12
Belgium	13.713	57.377	73%	3%	76%	10.626	5.40	335	0.17
Bulgaria	9.805	20.341	78%	5%	52%	7.660	2.66	29	0.70
Cyprus	65	2.726	97%	2%	98%	784	3.48	16	0.17
Denmark	26.987	20.516	83%	17%	-32%	5.461	3.76	227	0.09
Slovakia	5.622	18.074	72%	5%	69%	5.397	3.35	55	0.33
Slovenia	3.437	7.346	70%	10%	53%	2.018	3.64	34	0.21
Spain	30.180	146.812	84%	7%	79%	44.879	3.27	1.051	0.14
Estonia	4.423	6.029	93%	10%	27%	1.342	4.49	15	0.39
Finland	15.719	37.630	58%	23%	58%	5.289	7.12	180	0.21
France	134.021	270.272	53%	7%	50%	63.573	4.25	1.895	0.14
Greece	12.172	33.488	94%	5%	64%	11.193	2.99	228	0.15
Hungry	10.174	27.020	79%	5%	62%	10.056	2.69	101	0.27
Ireland	1.408	15.883	96%	3%	91%	4.357	3.65	191	0.08
Italy	25.899	183.452	91%	7%	86%	59.375	3.09	1.545	0.12
Latvia	1.797	4.764	65%	30%	62%	2.276	2.09	21	0.23
Lithuania	3.521	9.151	65%	9%	62%	3.376	2.71	28	0.32
Luxemburg	82	4.655	90%	3%	98%	480	9.70	36	0.13
Malta	0	946	100%	0%	100%	409	2.31	5	0.17
The Netherlands	60.992	84.542	93%	4%	28%	16.382	5.16	567	0.15
Poland	71.632	97.982	95%	5%	27%	38.121	2.57	311	0.32
Portugal	4.610	25.975	80%	18%	82%	10.608	2.45	163	0.16
United Kingdom	173.564	221.092	90%	2%	21%	60.996	3.62	2.047	0.11
Czech Republic	33.348	46.241	83%	5%	28%	10.334	4.47	127	0.36
Romania	27.619	40.083	83%	12%	31%	21.547	1.86	124	0.32
Sweden	33.068	50.564	35%	31%	35%	9.148	5.53	331	0.15
EU-27	849.551	1.806.336	79%	8%	53%	496.267	3.64	12.355	0.15
Basque Country	420	7.773	86%	5%	95%	2.148	3.62	66	0.12
Basque Country *(c)*	420	8.518	89%	5%	95%	2.148	3.97	66	0.13

a) Primary Energy Production.
b) Gross Domestic Energy Consumption (GDEC)
c) Energy intensity considered as GDEC/GDP.
d) Including primary energy related to electricity imports.

Table (16): Energy indicators of Basque Country and EU-27
Source: Elaborated with data from EUROSTAT, EUSTAT & EVE.

Another variable to be analysed in order to determine the degree of vulnerability of an economy to the increase in energy prices is its energy intensity, that is, the amount of energy needed to produce a unit of GDP. In 2007, the energy intensity of the Basque Country's economy, measured as the ratio of GDEC to GDP, was at 0.12 kilograms of oil equivalent (kgoe) per € (0.13 taking into account the primary energy related to imported electricity). This figure is similar to that of Austria or Italy, and slightly below the average value of the EU-27 and of Spain (0.14 kgoe/€) (see Table (16)). In per capita terms GDEC reached 3.63 toe in 2007 (3.97 toe including primary energy related to electricity imports), a figure close to that of the EU-27, but superior to that of Spain (3.27).

Even though the crisis will undoubtedly affect all economic sectors, it will not do so to the same extent. Obviously, an increase in oil prices will directly affect those sectors using that type of primary energy. This is especially the case for transportation as shown by Kerschner and Hubacek (2009), Kerschner, Prell et al. (submitted - see Chapter 2) and Lang and Dantas (unpublished).

In 2007, transportation of people and goods were responsible for 35% of the Basque Country's final energy consumption and for 86% of all oil products. Road transportation uses up to 95% of final energy consumption in the transportation sector. Moreover, in 2004, the Basque Country had a high-capacity motorway network of 245 km per million inhabitants (145 in the European Union 15, EU-15), a fleet of 79 vehicles per every thousand inhabitants destined to transport goods by road (64 in EU-15), and total energy consumption of transportation reached 762 toe for every million Basques (684 in the EU-15)[96]. These numbers show the high vulnerability of this sector, as well as that of the Basque Country as a whole, in the case of oil scarcity.

Today we live in a highly globalized economy, characterized by high levels of global labour division and a strong polarization of production and consumption centres. Considering the large share of modes of transportation fuelled by oil, in national and international trade and transportation of people, it can be expected that an increase in transportation costs will entail a general increase in the costs of certain goods and services, eventually raising their prices. The higher an industry's needs for mobility, be it due to its inputs or outputs, the more it will be affected by the crisis. From this point of view the sector's sensitivity to energy shortages will

[96] Elaborated with data from data bases of EUROSTAT and EUSTAT.

be determined by its transport intensity i.e. the joint distance travelled by all of its raw material inputs and its final products until they reach consumers, relative to its level of activity.

In order to analyse the degree of vulnerability of individual Basque economic sectors according to their mobility needs, it is necessary to look at their direct *and* indirect needs for transportation. For this purpose we have elaborated an Input-Output (IO) model which permits the calculation of total (direct and indirect) transportation needs (in kilometre per ton) associated with the activities of the different sectors of the Basque economy (see Appendix for technical details). The data we employed comes from the Basque Country's *input-output* tables and from statistics showing its trade with the rest of Spain and the rest of the world.

In general, the Basque economy is rather open, both regarding imports and exports. On the one hand, the limited endowment with natural resources relative to its economic structure, its GDP and population, encourage high levels of imports. According to our model for each € that the Basque economy generated in 2005, 0.77 kilometre per one ton of imports were involved on average (Table (17)). At the sector level and once more looking at raw material imports, sectors with the highest transport intensity relative to their production levels are: "fishing and agriculture"; the wood industry; "paper, editing and printing"; oil refining; chemical industry; "metallurgy and related by-products"; "transport material"; "other manufactured goods"; as well as "electricity, gas and water" (compare Table (17)).

On the other hand, those sectors which produce predominately for exports are very important for the Basque economy. Moreover, in many cases these sectors sell large amounts of goods to relatively distant markets. Overall, for every € the Basque economy exports, it is necessary to move 0.93 tons of merchandise per kilometre (Table (17)). Among the sectors that present the highest output related transport intensity we find: agriculture; fishing; "metallic and non-metallic minerals"; the food industry; "paper, editing and printing", oil refining, chemical industry, non-metallic industry, and "metallurgy and metallic products".

Regarding people's mobility, the crisis will especially affect those societies which are highly dependent on private vehicles within a region of low population densities. In general, an increasingly higher amount of personal disposable income will be necessary to cover mobility costs, which will induce a reduction in the consumption of other goods.

In the Basque Country, private vehicles are the main form of transportation used by citizens in their movements during working days (41%), a figure which could be considered large despite being below the State's average (45%) (see Table (18)). The Basque Country is the fourth Spanish Autonomous Community in terms of public transport use frequency, although its rate is below Spain's average. The average annual total expenditure on transport is about 1,598 €, which represents 12% of all expenditures. In absolute terms, this figure is slightly inferior to the average of all Spanish Autonomous Communities (1,676€).

With increasing oil prices, those of natural gas and electricity will also rise (Vücel and Guo 1994; Villar and Joutz 2006; Panagiotidis and Rutledge 2007) - 25% of electricity generated by the EU and 37% of that generated throughout the world stems from oil and natural gas. The direct effect on energy bills of industrial and tertiary sectors and households will be immediate and will add to a general escalation of prices. At the economic sector level, energy intensity (energy consumption per product unit) therefore becomes a key variable in order to analyse the effects of augmented oil prices. However, not only the direct energy intensity of each sector is important, but also its indirect one. That is, we must not only consider the energy used directly in each sector but also that which is needed to produce and transport intermediate goods.

		Vulnerability Factors					Full effect			
		Int. transport inputs	Int. transport products	Int. Total energy	Int. Direct energy	Demand Aspects	Exports		Domestic final demand	
							GVA Million €	Jobs	GVA Million €	Jobs
		t-km/€	t-km/€	kgep/€	kgep/€					
	País Vasco	0,77	0,93	0,18	0,03		**18,628**	**323,224**	**32,482**	**642,134**
		Dev. from the ref. value Basque Country					*Participation of the whole*			
1	Agriculture	32,9%	**505,1%**	26.4%	**206.2%**		0,2%	1,1%	0,2%	0,8%
2	Fishing and agriculture	**202,3%**	**125,4%**	**176.2%**	**1811.8%**		0,2%	0,5%	0,1%	0,1%
3	Gas and oil extraction	0,0%	0,0%	0.0%	0.0%	-	-	-	-	-
4	Metal and non-metal minerals	76,0%	**4361,1%**	47.7%	40.5%	***(a)***	0,1%	0,1%	0,0%	0,0%
5	Food industry	90,5%	**135,5%**	65.3%	40.5%		3,7%	4,4%	1,7%	2,1%
6	Textile and clothing industries	46,6%	23,1%	67.2%	86.1%		0,4%	0,9%	0,1%	0,1%
7	Shoe and Leather industries	57,9%	6,1%	87.1%	74.2%		0,0%	0,1%	0,0%	0,0%
8	Wood industry	**120,8%**	61,7%	34.4%	65.2%	***(a)***	1,1%	1,7%	0,0%	0,1%
9	Paper, editing and printing	**109,5%**	**158,2%**	96.5%	**361.4%**		2,8%	2,8%	0,4%	0,4%
10	Oil refining	**970,2%**	**558,9%**	**862.4%**	**323.2%**	***()***	1,3%	0,3%	0,3%	0,1%
11	Chemical industry	**116,9%**	**119,1%**	**110.3%**	**176.1%**		3,1%	2,2%	0,2%	0,1%
12	Rubber and plastic	93,1%	43,8%	**109.3%**	**106.2%**	***(b)***	**6,1%**	**5,9%**	0,1%	0,1%
13	Non-metallic industry	78,8%	**332,3%**	61.4%	**292.6%**	***(a)***	1,6%	1,4%	0,1%	0,0%
14	Metals and Metal Products	**153,2%**	**130,2%**	**169.4%**	**203.2%**	***(a), (b), (c)***	**23,3%**	**24,0%**	1,0%	1,0%
15	Machinery	96,9%	30,3%	**113.1%**	24.7%	*(c)*	**11,8%**	**12,9%**	0,7%	0,7%
16	Electric material	56,4%	42,4%	82.9%	18.2%	*(a)*	3,5%	4,0%	0,5%	0,6%
17	Transport material	**119,3%**	51,1%	**124.3%**	27.7%	***(b)***	**8,8%**	**8,7%**	0,9%	0,8%
18	Other manufactured goods	**113,8%**	21,8%	**122.5%**	75.7%	*(a)*	2,1%	2,7%	0,7%	0,9%
19	Electric energy, water and gas	**161,3%**	0,0%	**164.2%**	**521.4%**		0,4%	0,1%	2,0%	0,6%
20	Construction	76,4%	0,0%	61.3%	1.2%	***(a)***	0,0%	0,0%	**17,9%**	**16,7%**

21	Trade and repairs	34,5%	0,0%	48.1%	26.9%		**7,2%**	**6,8%**	**14,5%**	**17,6%**
22	Hotels and catering	57,7%	0,0%	62.5%	50.2%	*(b)*	0,9%	1,1%	**6,9%**	**7,7%**
23	Transport and communications	47,8%	0,0%	48.5%	**229.1%**	*(b)*	**6,3%**	**5,2%**	4,4%	3,3%
24	Banking and insurance	9,5%	0,0%	12.1%	5.3%		**5,3%**	2,1%	2,5%	1,2%
25	Business services	21,2%	0,0%	22.1%	5.1%	*(a)*	**9,4%**	**10,9%**	**15,8%**	**6,9%**
26	Public Administration	46,6%	0,0%	61.4%	51.6%		0,0%	0,0%	**9,1%**	**10,2%**
27	Education	22,3%	0,0%	30.1%	18.6%		0,0%	0,0%	**6,4%**	**9,4%**
28	Healthcare and social services	25,8%	0,0%	39.9%	14.9%		0,0%	0,0%	**8,1%**	**7,6%**
29	Personal services	40,3%	0,0%	66.2%	39.7%		0,1%	0,2%	4,8%	**6,6%**
30	Domestic service	0,0%	0,0%	0.0%	0.0%		0,0%	0,0%	0,7%	4,2%
31	Extraterritorial organizations	-	-	0.0%	0.0%	-	-	-	-	-

(a) Construction related sector.
(b) Sector associated to transport and automobiles.
(c) Investment related sector.

Table (17): Macroeconomic analysis of the Basque Country's economic vulnerability, GVA and total employment related to exports and domestic final demand (2005)
Source: Elaborated with data from EUROSTAT, EUSTAT & EVE.

	% of journeys per mode (2008)			% Transport expenditure / total expenditure (2007)	Transport expenditure (€) 2007
	Public transport	Private transport	Walking		
Andalusia	12.0%	47.1%	38.0%	15.7%	1.633
Aragon	17.9%	38.2%	41.4%	12.9%	1.499
Asturias (Principado de)	21.7%	42.9%	34.2%	13.8%	1.556
Balears (Illes)	11.9%	51.1%	32.2%	14.6%	1.933
Canary islands	30.5%	62.0%	5.2%	17.0%	1.765
Cantabria	17.1%	47.8%	33.5%	15.8%	1.840
Castilla - La Mancha	5.8%	46.3%	45.8%	13.5%	1.691
Castilla y León	8.6%	39.5%	49.1%	15.1%	1.348
Catalonia	28.4%	43.5%	23.5%	12.8%	1.644
Ceuta and Melilla	13.3%	51.5%	34.0%	14.0%	1.787
Comunidad Valenciana	12.3%	42.4%	42.7%	15.3%	1.661
Extremadura	7.1%	40.6%	50.1%	18.0%	1.541
Galicia	18.8%	60.0%	19.3%	14.8%	1.812
Madrid (Comunidad de)	49.8%	37.3%	11.7%	13.5%	1.800
Murcia (Región de)	10.8%	57.4%	29.1%	16.4%	1.787
Navarre (Comunidad Foral de)	20.3%	46.3%	30.7%	13.4%	1.591
Rioja (La)	9.1%	40.1%	47.9%	14.2%	1.307
Spain	21.7%	45.3%	30.3%	14.4%	1.676
Basque Country	**28.0%**	**41.2%**	**29.7%**	**12.0%**	**1.598**

Table (18): Private mobility in Spain
Source: prepared by the authors from INE (INE 2009; INE 2009)

As we did previously for analysing transportation requirements, we use an IO methodology in order to study the total energy needs (direct and indirect) of the Basque economy. In this case we employed a multi-regional input-output model (Basque Country, rest of Spain, rest of the world) to calculate the total primary energy incorporated in goods and services produced by the Basque economy (see Appendix for technical details).

In 2005 the total energy intensity of the Basque economy, that is the total energy needed to produce one Euro worth of output, amounted to 0.18 kgoe, a figure which is six times the one obtained if we only count the energy used directly by each sector (Table (17)). Relative to the whole Basque economy, six sectors present a total energy intensity above average: "fishing and agriculture"; oil refining; chemical industry; "rubber and plastic"; "metallurgy and metal products"; machinery; transport material; "other manufactured goods"; and "electricity, gas and water". If we only consider the energy which is used directly two more sectors lie above the national average: "paper, editing and printing industries"; as well as "transport and communication sectors".

On the other hand, the price surges of energy products will translate to the whole economy, inducing an inflationary process (LeBlanc and Chinn 2004). Each day a larger share of disposable income will be needed to pay for energy. This share of income is transferred to producer countries, deteriorating the balance of trade and pushing down exchange rates (Clonan 2008). This means that the purchasing power of oil importing countries would decrease and demand for oil eventually diminish, causing at the same time an economic downturn. This decrease in demand would be compensated, only partially, by a consumption rise in oil producing countries, given that their marginal propensity to consume is lower than that of importing countries.

Unquestionably, such a crisis would rapidly transcend to the social level. Lower economic growth could cause higher rates of unemployment. The rise on living costs would be accompanied by wage demands by the working classes, which would contribute to increased production costs, eventually leading to layoffs, aggravating unemployment issues. Under such circumstances it is more than likely that social tensions and conflict would emerge (Leder and Shapiro 2008).[97]

The rise in costs and the decrease in sales would squeeze business margins. Empty order books would provoke freezing investments, which would affect the demand for capital goods. Moreover the general awareness of the critical situation by entrepreneurs and consumers would have negative effects on their expectations. This would intensify the crisis, for the deterioration of such expectations will encourage the reduction of investment and

[97] It's not unreasonable to believe that these tensions may transcend national boundaries, creating international armed conflicts in order to control the remaining resources to ensure appropriate oil supply (Friedrichs 2010).

consumption levels, jeopardizing any possible economic recovery. Even before that it would be difficult for troubled sectors to secure fund on financial markets, causing liquidity crises and bankruptcies, as the current example of German container shipping industry shows (Evans-Pritchard 2012).

Financial markets would not be immune to such a crises of course, rather the contrary is true and they may be the first ones to make the general downturn visible. The diminution of investment, production and consumption levels, the erosion on corporate profits and shift in expectations would directly affect stock markets and the financial system. Restrictions on credit would induce further contraction in consumption and investment (Kaufmann, Gonzalez et al. 2010).

Obviously, the final demand for energy will fall, affecting directly the energy sectors. Also, in moments of economic downturn, the demand which is usually mostly affected is that of consumer durables and capital goods. In the first case this is due to a reduction in household expenses. Within these types of goods, a decrease in demand would probably be more significant for those which need a lot of energy (automobiles, domestic appliance, etc.). In the case of capital goods, the justification of a reduction in their demand lies in companies' mitigated investment due to negative future prospects as already mentioned.

Therefore, in order to analyse an economy's vulnerability to peak oil it is extremely important to study the type of goods and services it produces (Table (17)). In the event of an energy price increase, the final demand of oil refining services, electricity, gas and water, would be especially affected.

The demand of goods belonging to the "rubber and plastic" sectors, the "metallurgy and metal products" sectors and that of transport materials would suffer the effects of the crisis, due to the lack of sales and production of automobiles.

On a global scale, one of the sectors that will more intensely suffer the consequences of the crisis will be tourism (Yeoman, Lennon et al. 2007; Logar and van den Bergh unpublished). This is because, in the first place, tourism demand depends, to a large extent, on the development of transport prices. On the other hand, the lowering of people's disposable income will erode this sector's vitality. Travelling could be seen as a luxury good, which can easily be eliminated from family budgets. All of which will especially disrupt the hotel and catering industries.

The construction and real estate business could also be seen as a vulnerable sector. First, the bursting of the Spanish housing bubble (Naredo 2010; Pérez 2010) has already critically affected this economic activity. In the event of high oil prices, the deterioration of expectations, the loss of purchasing power and the lack of credits and mortgages would aggravate this situation. This fact would have knock-on-effects to industries, which enjoy close links to the housing sectors: metal and non-metal minerals, the wood industry, non-metals industry (construction materials), metallurgy and metal products, electronic equipment (domestic appliances), other manufactured products (where the production of furniture represents 79% of that sector's gross value added (GVA)) and services for companies (the real estate activities represent 47% of that sector's GVA).

Finally, the low investment rate will specifically affect sectors, which mainly produce capital goods, such as metallurgy metal products, as well as machinery.

We must underline the fact that the effects of the crisis would depend to some extent on each country or region's ability to adapt to the situation by specific sectorial and economic policies (energy-wise, transport industry, etc.) for mitigating the crisis. States and regions which are especially open to foreign trade would find their room for manoeuvre significantly reduced, because the crisis' impact on them will be determined by the economic situation in other countries.

The last four columns of Table (19) represent GVA and jobs which are directly and indirectly related to each individuals sector's exports and domestic final demand. In 2005 36% of the Basque Country's GVA (18,628 million euros) and 33% of its employment (323,224 job positions) were a direct or indirect result of products sold to the rest of Spain and the world. A majority of those exports originate from sectors which are especially sensitive to peak oil. This aspect is of particular importance in order to determine vulnerability levels, because it implies that a large area of economic activity is directly influenced by the demand of Basque products in other regions and, therefore, the Public Administration's level of autonomy to actively stimulate such demand is minimal. Also, we must bear in mind that the level of final inland demand is conditioned by those export-related incomes, so that an export reduction would manifest itself in a contraction of overall final inland demand and, thus, of GVA and employment rate.

Very high			High			Average			Low		
	GVA	Jobs		GVA	Jobs		GVA	Jobs		GVA	Jobs
Fishing and agriculture	0,1%	0,3%	Agriculture and farming	0,2%	0,9%	Wood industry	0,4%	0,6%	Textile and clothing	0,2%	0,4%
Oil refining	0,7%	0,1%	Metal and non-metal min.	0,0%	0,0%	Food industry	2,4%	2,9%	Leather and shoe industry	0,0%	0,0%
Chemical industry	1,2%	0,8%	Paper, editing and printing	1,3%	1,2%	Wood industry	0,4%	0,6%	Trade and repairs	11,9%	14,0%
Metals and Metal products	9,1%	8,7%	Rubber and plastic	2,3%	2,0%	Machinery	4,8%	4,8%	Banking and insurance	3,5%	1,5%
Transport material	3,8%	3,4%	Non-metalic industry	0,6%	0,5%	Electric material	1,6%	1,7%	Personal services	3,1%	4,4%
Electrical energy, water and gas	1,4%	0,4%	Transport and communications	5,1%	4,0%	Other manufactures	1,2%	1,5%			
Construction	11,4%	11,1%	Business services	13,5%	8,2%	Hotels and catering	4,7%	5,5%			
						Public Administration	5,8%	6,8%			
						Education	4,1%	6,2%			
						Healthcare and social services	5,1%	5,1%			
Total	**27.7%**	**24.8%**		**23,0%**	**16,8%**		**30.5%**	**35,7%**		**18.7%**	**20,3%**

Table (19): Vulnerability by sectors (GVA and employment)

By taking into account the above information we could classify each sector of the Basque economy according to its vulnerability in the following fashion Table (19).

- High or very high vulnerability: we would be talking of sectors with elevated energy and transport intensities, whose production is connected, in some cases, to goods whose demand will drastically recede in an energy scarcity scenario. These sectors represent roughly

51% of GVA and 41% of employment in the region. The sectors included in this category are: "fishing and agriculture"; oil refining; the chemical industry; "metallurgy and metal products"; transport material; "electricity, gas and water"; construction; farming; "metal and non-metal minerals"; "paper, editing and printing"; "rubber and plastic"; "non-metal industry"; "transport and communications"; and business services.

- Average vulnerability: these are sectors with high risk scores in some of the vulnerability factors mentioned above. They include: agriculture; farming; the food industry; wood industry; machinery; electric material; "other manufactures"; as well as the "hotel and restaurant business". It should not go without mentioning though that public services such as Public Administration, Education, Healthcare and social services will be affected indirectly by reduced tax revenues and an increase in unemployment benefits, which is not taken into account here.
- Finally, sectors with low vulnerability scores according to our analyses are: "the textile and clothing industry"; "the leather and shoe industry"; "wholesale and retail trade and repairs", "banking and insurance sector", as well as "personal services".

1.6.1 Basque vulnerability to Peak-Oil – concluding remarks and recommendations

The Basque Country will not remain at the margins of the coming Peak-Oil crises. The region's socioeconomic structure is also based on the abundance of cheap oil. Public policies as a whole (transport, regional planning, energy, industry, etc.), similarly to most other regions and countries in the west, have been designed with no regard to the possibility of future energy scarcity. However the Basque economy seems particularly vulnerable in this context, as it combines several alarming characteristics: its considerable energy dependence; the significant energy and transport intensity of some of its most representative sectors; the supremacy of road transport and the close links between the activities of certain sectors with products whose demand is particularly sensitive to oil prices.

This article is only a first attempt for estimating the possible impacts peak oil may bring upon the Basque economy. However, the transcendence and immanence of the challenge we are facing requires a more in-depth analysis. It is therefore of paramount importance for the short term to develop a vulnerability analysis at every level (economic, sectorial, social, institutional, etc.) and to initiate a strategic planning process to face the transition towards a more sustainable model of society (Bermejo 2008).

Likewise, the proximity or imminence of peak oil raises the need to start “buying time” to all this transition to be as smooth as possible. We must elaborate and implement an emergency plan as soon as possible (Hirsch, Bezdek et al. 2005). The measures included in this plan must be aimed at saving resources and becoming more energy efficient. That is, we should use considerably less energy, and in a more efficient way.

In the long term, peak oil poses an enormous predicament: building a new socioeconomic model based on austerity, sufficiency and renewable energy. We have to plan this transition for society as a whole, introducing the energy challenge in every policy action we take, working towards long term tactics. Each day, more societies are following such guidelines (Bermejo 2009; Dodson and Sipe 2009; Lerch 2009) and the Basque Country cannot remain aloof of these developments.

1.6.2 Appendix I: The Basque Country’s vulnerability to Peak Oil: METHODS

Multi-regional Input-Output (MRIO) models have been widely used to analyze the environmental consequences of trade (see Wiedmann 2009; Wiedmann, Wilting et al. 2011 for a comprehensive revision of the literature and the existing databases). In our case, we have useed a MRIO to calculate the primary energy embodied in final demand of the Basque Country.

We distinguished 3 regions in or model: the Basque Country (region 1), the Rest of Spain (region 2), and the Rest of the World (RoW).

The starting point of the model is the MRIO table. This table describes the flows of goods between all the individual sectors and countries and their use by final consumers. We can distinguish 3 main components in the MRIO table:

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11} & \mathbf{Z}^{12} & \mathbf{Z}^{12} \\ \mathbf{Z}^{21} & \mathbf{Z}^{22} & \mathbf{Z}^{23} \\ \mathbf{Z}^{31} & \mathbf{Z}^{32} & \mathbf{Z}^{33} \end{bmatrix} \quad \mathbf{f} = \begin{bmatrix} \mathbf{f}^{1} \\ \mathbf{f}^{2} \\ \mathbf{f}^{3} \end{bmatrix} = \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \mathbf{f}^{13} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \mathbf{f}^{23} \\ \mathbf{f}^{31} + \mathbf{f}^{32} + \mathbf{f}^{33} \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} \mathbf{x}^{1} \\ \mathbf{x}^{2} \\ \mathbf{x}^{3} \end{bmatrix}$$

where Z^{rs} gives the intermediate deliveries from country r to country s, f^{rs} denotes the final demands in country s for goods produced by country r, and x^{r} gives the gross output in country r. We assume now that region 1 is small compared to the other 2 regions and that $\mathbf{Z}^{1s}$ is negligible compared to the size of the other 2 regions. In order o balanced the MRIO table we will assume that all the exports form region 1 to the other region are final exports. Therefore, the components of the MRIO can be expressed as

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11} & \mathbf{0} & \mathbf{0} \\ \mathbf{Z}^{21} & \mathbf{Z}^{22} & \mathbf{Z}^{23} \\ \mathbf{Z}^{31} & \mathbf{Z}^{32} & \mathbf{Z}^{33} \end{bmatrix} \quad \mathbf{f} = \begin{bmatrix} \mathbf{f}^{1} \\ \mathbf{f}^{2} \\ \mathbf{f}^{3} \end{bmatrix} = \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \mathbf{f}^{13} + \mathbf{Z}^{12}\mathbf{i} + \mathbf{Z}^{13}\mathbf{i} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \mathbf{f}^{23} \\ \mathbf{f}^{31} + \mathbf{f}^{32} + \mathbf{f}^{33} \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} \mathbf{x}^{1} \\ \mathbf{x}^{2} \\ \mathbf{x}^{3} \end{bmatrix}$$

where $\mathbf{i}$ is the column summation vector. The relation between $\mathbf{x}$, $\mathbf{Z}$ and $\mathbf{f}$ is defined by the accounting equation $\mathbf{x} = \mathbf{Zi} + \mathbf{f}$.

Finally, let assume that the MRIO table is extended to include a vector of sectoral primary energy extraction by $\mathbf{g}$:

$$\mathbf{g} = \begin{bmatrix} \mathbf{g}^{1} \\ \mathbf{g}^{2} \\ \mathbf{g}^{3} \end{bmatrix}$$

We can obtain the input coefficients $\mathbf{A}^{rs} = \mathbf{Z}^{rs}\left(\hat{\mathbf{x}}^{s}\right)^{-1}$, where $\left(\hat{\mathbf{x}}^{s}\right)^{-1}$ denotes the inverse of the diagonal matrix of the vector of total output. Likewise, the primary energy coefficients are defined as $\mathbf{e}^{r} = \left(\hat{\mathbf{x}}^{r}\right)^{-1}\mathbf{g}^{r}$.

The accounting equation can now be written as the standard input-output model: $\mathbf{x} = \mathbf{Ax} + \mathbf{f}$. For arbitrary final demands $\mathbf{f}$, the solution to the this model is given by $\mathbf{x} = \mathbf{Lf}$, where $\mathbf{L} \equiv (\mathbf{I - A})^{\mathbf{-1}}$ denotes the Leontief inverse. The primary energy would be given by

$$\mathbf{g} = \hat{\mathbf{e}}\mathbf{x} = \hat{\mathbf{e}}\mathbf{Lf} \tag{1}$$

We can write (1) in its partitionate form as

$$\begin{bmatrix} \mathbf{g}^{1} \\ \mathbf{g}^{2} \\ \mathbf{g}^{3} \end{bmatrix} = \begin{bmatrix} \mathbf{e}^{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{e}^{2} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{e}^{3} \end{bmatrix} \begin{bmatrix} \mathbf{L}^{11} & \mathbf{0} & \mathbf{0} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \mathbf{L}^{23} \\ \mathbf{L}^{31} & \mathbf{L}^{32} & \mathbf{L}^{33} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \mathbf{f}^{13} + \mathbf{Z}^{12}\mathbf{i} + \mathbf{Z}^{13}\mathbf{i} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \mathbf{f}^{23} \\ \mathbf{f}^{31} + \mathbf{f}^{32} + \mathbf{f}^{33} \end{bmatrix} \tag{2}$$

From (2) we can calculate the total primary energy embodied in the goods produced by the Basque Country (region 1):

$$\mathbf{h}^{1} = \left(\mathbf{e}^{1}\mathbf{L}^{11} + \mathbf{e}^{2}\mathbf{L}^{21} + \mathbf{e}^{3}\mathbf{L}^{31}\right)\left(\mathbf{f}^{1} + \mathbf{Z}^{12}\mathbf{i} + \mathbf{f}^{13}\mathbf{i}\right) = \mathbf{tot\_int}^{1}\left(\mathbf{f}^{1} + \mathbf{Z}^{12}\mathbf{i} + \mathbf{f}^{13}\mathbf{i}\right) \tag{3}$$

Where $\mathbf{tot\_int}^{1} = \left(\mathbf{e}^{1}\mathbf{L}^{11} + \mathbf{e}^{2}\mathbf{L}^{21} + \mathbf{e}^{3}\mathbf{L}^{31}\right)$ is the total energy intensity as

Final, we have defined the direct energy intensity as the quotient between the final energy consumption by sector and the gross output by sector.

The main data sources fo this calculations are the Input Output tables of the Basque Country for the year 2005 from the Basque Statistics Institute (EUSTAT) the energy accounts of the Basque Country developed by Labein Tecnalia for the Basque Government, and the GTAP database for the data of Spain and the World.

For the calculation of the transport requirements we have used a single-region input output model. The first step consists on calculating the total transport linked to the flows of goods with other regions, in terms of tonnes-kilometre.

Let be d_RoS_r the distance in kilometres by road between the capitals cities of the r provinces of Spain and the capital city of the Basque Country and d_RoW_s, the distance between the capital cities of the s countries of the world an the capital city Basque Country[98]. Similarly let be, $w\_imp\_RoS_{ir}$, $w\_imp\_RoW_{is}$, $w\_\exp\_RoS_{ir}$ and $w\_\exp\_RoW_{is}$ the weight of the intermediate imports and exports by sector *i* of the Basque Country with other Spanish and with other countries[99]. Then, the total transport linked to intermediate imports of each sector and the transport linked to exports is:

$$tot\_tkm\_imp_i = \sum_r \left(d\_RoS_r * w\_imp\_RoS_{ir}\right) + \sum_s \left(d\_RoW_s * w\_imp\_RoW_{is}\right)$$

$$tot\_tkm\_\exp_i = \sum_r \left(d\_RoS_r * w\_\exp\_RoS_{ir}\right) + \sum_s \left(d\_RoW_s * w\_\exp\_RoW_{is}\right)$$

Let be $\mathbf{t}$ the vector of transport coefficients resulting from dividing the transport linked to intermediate imports of each sector by its total output (i.e. transport intensity of imported inputs), the we can calculate the transport embodied in the final demand of goods produced in region 1 using the Leontief model:

$$\mathbf{k}^1 = \hat{\mathbf{t}}^1\mathbf{L}^1\mathbf{f}^1 \; \mathbf{g} = \hat{\mathbf{e}}\mathbf{x} = \hat{\mathbf{e}}\mathbf{L}\mathbf{f}$$

---

[98] This information was proficed by Minuartia Stucis Ambientals

[99] Data on international trade was provided by EUSTAT (NSI of the Basque COuntr). Data of trade with the rests of Spain was obtained form c-intereg.com

Where the element k_i of $\mathbf{k}^1$ denotes the total transport linked to the intermediate imports needed to produce the final goods produced by sector *i*. We define now the total transport linked to the final demand of goods produced by sector *i*, as the sum of the total transport linked to the intermediate imports needed to produced those goods plus the emissions needed to transport those goods to other regions:

$$tot\_tkm_i = k_i + tot\_tkm\_\exp_i$$

Finally we obtain the total transport intensities o products by dividing the total transport requirements (in t-km) by the total final demand in monetary units.

PAPER I[100]

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Erratum

Erratum to "Assessing the suitability of Input-Output analysis for enhancing our understanding of potential effects of Peak-Oil" [Energy (2008) 34: 284–290]

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Due to a typesetting error, several errors throughout the article were not corrected properly. For the reader's convenience, the article follows, in its entirety, in the format in which it was intended to appear.

The publisher deeply regrets this error.

Assessing the suitability of input–output analysis for enhancing our understanding of potential economic effects of Peak Oil

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ABSTRACT

Given recent developments on energy markets and skyrocketing oil prices, we argue for an urgent need to study the potential effects of world oil production reaching a maximum (Peak Oil) in order to facilitate the development of adaptation policies. We consider input–output (IO) modelling as a powerful tool for this purpose. However, the standard Leontief type model implicitly assumes that all necessary inputs to satisfy a given demand can and will be supplied. This is problematic if the availability of certain key inputs becomes restricted and it is therefore only of limited usefulness for the study of the phenomenon of Peak Oil. Hence this paper firstly reviews two alternative modelling tools within the IO framework: supply-driven and mixed models. The former has been severely criticised for its problematic assumption of perfect factor substitution and perfect elasticity of demand as revealed by Oosterhaven [Oosterhaven J. On the plausibility of the supply-driven IO model. J Reg Sci 1988; 28:203–17. [1]]. The supply-constrained model on the other hand proved well suited to analyse the quantity dimension of Peak Oil and is therefore applied empirically in the second part of the paper, using data for the UK, Japanese and Chilean economy. Results show how differences in net-oil exporting and net-oil importing countries are clearly visible in terms of final demand. Industries, most affected in all countries, include transportation, electricity production and financial and trade services.

1. Introduction

Given the potential scale and implication for the world economy the phenomenon of Peak Oil has received very little attention in the media, by policy makers and by academia. Some discussion is taking place around the specific issue of when exactly oil and gas

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Assessing the suitability of Input-Output analysis for enhancing our understanding of potential effects of Peak-Oil[101]

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1.7 Abstract

Given recent developments on energy markets and skyrocketing oil prices, we argue for an urgent need to study the potential effects of world oil production reaching a maximum (Peak Oil) in order to facilitate the development of adaptation policies. We consider input–output (IO) modelling as a powerful tool for this purpose. However, the standard Leontief type model implicitly assumes that all necessary inputs to satisfy a given demand can and will be supplied. This is problematic if the availability of certain key inputs becomes restricted and it is therefore only of limited usefulness for the study of the phenomenon of Peak Oil. Hence this paper firstly reviews two alternative modelling tools within the IO framework: supply-driven and mixed models. The former has been severely criticised for its problematic assumption of perfect factor substitution and perfect elasticity of demand as revealed by Oosterhaven (1988). The supply-constrained model on the other hand proved well suited to analyse the quantity dimension of Peak Oil and is therefore applied empirically in the second part of the paper, using data for the UK, Japanese and Chilean economy. Results show how differences in net-oil exporting and net-oil importing countries are clearly visible in terms of final demand. Industries, most affected in all countries, include transportation, electricity production and financial and trade services.

1.8 Keywords

Input-Output (IO) Analysis, Supply-Driven and Supply Constrained IO Analysis, Peak Oil, Leontief price model, Gosh model, systems approach.

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1.9 Introduction

Given the potential scale and implication for the world economy the phenomenon of Peak Oil has received very little attention in the media, by policy makers and by academia. Some discussion is taking place around the specific issue of when exactly oil and gas production are going to peak (compare World Watch magazine January/February 2006), but these arguments are often of little scientific content and seem motivated by reasons other than to provide an objective public debate. On the one side there are those who argue that Peak Oil is imminent, and urgent action has to be taken as soon as possible to reduce consumption and to prepare ourselves for the radical economic changes that are assumed to be caused by the phenomenon (e.g.: Campbell and Laherrere 1998; Deffeyes 2001; Duncan 2003; Hirsch, Bezdek et al. 2005; Aleklett 2006). The group characterised by this more pessimist view is sometimes referred to as the "geologists", because they believe that geology will be the determining factor for the timing of Peak Oil. Colin Campbell, the founder of the Association for the Study of Peak Oil and Gas (ASPO), is at the forefront of this group. On the other side, there are the "optimists" who accuse the former of doomsday politics, of reviving a "recurring myth" (Caveny 2006) or of practicing a "catastrophic cult" (Smil 2006). They are known as the "economists" of this debate, because they believe that market mechanisms and human ingenuity will bring about alternative sources of energy to replace energy gained from fossil fuels altogether, before Peak Oil seriously affects economic growth (Greene, Hopson et al. 2006).

It is believed here that what lies beneath this optimism is the fact that absolute scarcity of resources does not seem to be accepted by orthodox science and the human society in general. Until now humanity always seems to have found new resources when others became scarce. Technological innovation is believed to solve not only the problem of resource depletion, but also the environmental damage caused by it. Orthodox economics is a major representative of this ideology. It is argued (e.g.: Barnett and Morse 1963) that scarcity of matter and energy is only ever relative and not absolute. Relative scarcity means that one resource is only scarce relative to another resource, or the same resource but of a different (lower) quality. It can be overcome by substitution, whereby relatively scarce resources are eventually substituted by relatively abundant ones. Resources are therefore unlimited in total and merely non-homogenous in quality. The price mechanism will automatically make consumption switch from the scarcer resource to an alternative.

Orthodox economists tend to use this rationale to support their claims of unlimited economic growth. Ecological Economics, on the other hand, insists that ultimate means in the form of low-entropy matter/energy are scarce in an absolute sense, i.e. there are absolute limits beyond which availability is nil (e.g.: Daly 1992). A direct result thereof is that economic growth is equally limited. In this study absolute resource (low entropy) scarcity is accepted as a fact. Hence the goal of this study is not to enter the polemic discussion of when Peak Oil is going to occur in time. Fact is that it will occur at some point and that so far there do not seem to be any alternative sources of energy forthcoming, which seem to have the power to replace oil (compare Brown 2008). History already provides evidence of the dramatic effects of oil and gas shortages: The impacts of the two oil shocks in the late 1970s and early 1980s upon world economies were felt for almost a decade after. Consequently, the urgent need for widespread academic efforts to study the potential impacts of Peak Oil upon world economies is advocated here.

This involves most of all starting to develop and implement policies to reduce resource consumption, not only for the sake of preventing possible economic crises, but also for the sake of reducing environmental impacts of economic activity. A precondition for such an undertaking - and the challenge for science - is to explore, develop and apply tools for enhancing our understanding of the potential effects of Peak Oil. Very little is known about how economies will react once supply of oil and gas becomes physically limited. Surely, one could look at oil and gas consumption balance sheets, to predict which sectors are going to be most affected by Peak Oil. However, such a procedure disregards the complex interdependencies of industries within an economy. It would only be able to show the direct effects but indirect, knock-on or ripple effects are ignored. Input–output (IO) analysis is a framework, which allows capturing inter-industry linkages and to measure the direct and also the indirect effects of external shocks.

Nevertheless, as will be argued in the next section, the traditional demand-driven Leontief model is only of limited suitability for analysing resource constraints, as it assumes unrestricted supply of factor inputs. The same section, therefore, reviews two alternative approaches: the supply-driven and the supply-constrained model. After arriving at the conclusion that a mixed or supply-constrained model would be appropriate for analysing the quantity dimension of Peak Oil, the method is applied to IO tables of the UK, Japan and Chile. The impact of a sudden 10% reduction of output in the "crude oil and natural gas extraction" and "petroleum refining" sectors upon the output of the rest of the economy and upon their own final demands are measured; the results presented in Section 1.12 and its limitations discussed in Section 1.13. Section 1.14 concludes.

1.10 Review of methods

Standard IO analysis was developed by Nobel prize laureate Leontief (1936; 1941). Today, IO tables are being generated on a regular basis for all OECD countries, and the standardization of the framework has been promoted by the United Nations. More recently, it has become a popular tool for ecological–economic analysis (i.e. for studying nature–economy relationships), for Industrial Ecology and for Life Cycle Analysis. The basic IO transaction table consists, firstly, of rows showing "Who gives to whom?" and columns showing "Who receives from whom?" in an economy. The static Leontief model is driven entirely by the final demand matrix [Y]. This matrix determines total outputs [x], intermediate inputs [Z] and primary inputs [W] via a set of technical coefficients (see Table (20) for the general outline of an IO table). Usually the question to be answered in demand-side IO modelling is the following: If final demand from one or more of the exogenous sectors (households, government, etc.) is expected to increase or decrease in the future, how would this affect the total output necessary to satisfy this new demand and its ripple effects throughout the economy?

One of the assumptions underlying the demand-driven nature of the standard IO model is that all input requirements for the production of some exogenously given demand will automatically and instantaneously (i.e. within the given statistical year) be met. This is only justifiable, given the existence of unused capacity and very elastic factor–supply curves (Giarratani 1976), which usually will not be the case. This feature renders the standard approach unsuitable for the analysis of supply constraints. Intuitively the most attractive alternative to the demand-driven model is the supply-driven IO approach first proposed by Ghosh (1958). The basic idea behind this approach is that if, for example, less of a scarce input (e.g. labour) is fed into the system, the knock-on effects will result in output decreases throughout all economic sectors. Hence it is the supply matrix [W], which drives the model and determines the endogenous variables Z, Y and x.

However, on the industry level the model implicitly assumes perfect substitutability between factors. Intuitively this may be regarded plausible as the economy is partly substituting the reduction of available manpower with other inputs. However, this substitution does not respect physical realities and the process does not take into account the properties of the inputs. Moreover, in combination with the assumption of cost minimization, industries would - depending on relative prices - always choose to have only one input (the cheapest) or input combinations would not be unique (Gruver 1989). At the level of the whole economy the model assumes perfect elasticity of demand, which means that final (households, governments, etc.) and intermediate (inter-industry) demand will adapt smoothly to any changes in supply. It ignores important interdependencies between certain products, such as it is very unlikely that sales of cars, to choose one example, would increase if there was not enough fuel available. Hence we therefore agree with the conclusions made by Oosterhaven (1988) in his paper “Plausibility of Supply-Side I-O Models” that the supply-driven model may be unsuitable for both, general descriptions of the working of an economy and for analysing the effects of supply constraints. However, we believe that there may be circumstances, where these problematic assumptions might be less unrealistic and the subject may merit further analysis.

The second model alternative to the traditional Leontief IO model to be reviewed here is the supply-constrained or mixed IO model. So far exogenous variables were either final demand [Y] in the demand-driven or value added [W] in the supply-driven model. This restricts the scientific efforts to observe the impacts on total output [x] of either changes in final demand (due to changing consumer tastes, government spending, etc.) or value added (due to strikes, import embargoes, etc.), respectively. This is particularly restrictive for impact studies of supply shortages such as in the case of Peak Oil. Here it may be desirable to exogenise the sector that is potentially causing the disruption. IO models with mixed exogenous and endogenous variables (therefore the name mixed models) provide a solution to this problem. In the literature they have firstly been described by Stone (Stone 1961, p. 98). Instead of estimating changes in sectoral outputs due to changes in final demand (traditional Leontief model) or value added (Ghosh model), mixed models estimate the impacts on unconstrained sectors given some reduced outputs of the supply-constrained sectors. This approach allows the final demand of some sectors and gross output of the remaining sectors to be specified exogenously.

The procedure is well explained in Miller and Blair (1985, p. 330ff) and we will therefore only provide a schematic representation of the model and the underlying equation. The IO system is basically partitioned into supply-constrained and non-supply-constrained sectors. This is illustrated for a simple three sector economy with output restricted energy sectors in Table (20). Using basic matrix algebra for partitioned matrices one can then derive Eq. (124).for the general case. The individual variables, vectors and sub-matrices of this equation are explained in Table (21). There are now n total sectors of which one or more are exogenous. The labelling of the sectors indicates that the first k sectors contain the endogenous elements and the last (n–k) sectors the exogenous elements.

(124)
$$\begin{bmatrix} \mathbf{x}_{\mathbf{no}} \\ \mathbf{y}_{\mathbf{co}} \end{bmatrix} = \begin{bmatrix} \mathbf{P} & \mathbf{0} \\ \mathbf{R} & -\mathbf{I} \end{bmatrix}^{-1} \times \begin{bmatrix} \mathbf{I} & \mathbf{Q} \\ \mathbf{O} & \mathbf{S} \end{bmatrix} \times \begin{bmatrix} \bar{\mathbf{y}}_{\mathbf{no}} \\ \bar{\mathbf{x}}_{\mathbf{co}} \end{bmatrix}$$

			Processing sectors			**Purchase Sectors Final Demand (Y)**		**Total Out-put (x)** (*i*)
			non-constrained		**con-str'nd**			
		to (j) / **from (i)**	Agri-culture	Manu-factor-ing	Energy	House-holds etc.	Ex-ports (**e**)	
Pro-cessing Sectors (Z) (*I* x *J*)	**non-constrained**	Agriculture	z_{11}	z_{12}	z_{13}	y_1	e_1	x_1
		Manufacturing	z_{21}	z_{22}	z_{23}	y_2	e_2	x_2
	constrained	Energy sectors	z_{31}	z_{32}	z_{33}	y_3	e_3	x_3
Payments Sector (W)		Value added	w_1	w_2	w_3			
		Imports (**m**)	m_1	m_2	m_3			
Total Outlays (x') (*i*)			x_1	x_2	x_3			

Table (20): Partitioning the IO table in constrained and unconstrained sectors.

P…...	($k \times k$) matrix containing the elements from the first k rows and the first k columns in ($\mathbf{I}-\mathbf{A}$). It provides the average expenditure propensities of non-supply constrained sectors.
R…...	[$(n-k) \times k$] matrix containing elements from the last ($n-k$) rows and the first k columns of ($-\mathbf{A}$). It provides average expenditure propensities of non-supply constrained sectors on supply constrained sector output.
$\mathbf{x}_{\mathbf{no}}$ …	k-element column vector with elements x_1 through x_k; representing endogenous total output of non-supply constrained sectors.
$\mathbf{y}_{\mathbf{co}}$ …	($n-k$)-element column vector with elements y_{k+1} through y_n, representing endogenous final demand of supply constrained sectors.
Q.......	[$k \times (n-k)$] matrix of elements from the last ($n-k$) rows and first k columns of (**A**) and represents supply constrained sector expenditure propensities on non-supply constrained sector output.
S…...	[$(n-k) \times (n-k)$] matrix of elements from the last ($n-k$) rows and columns of $-(\mathbf{I}-\mathbf{A})$, and represents average expenditure propensities among supply constrained sectors.
$\bar{\mathbf{y}}_{\mathbf{no}}$ …	k-element column vector of elements y_1 through y_k, representing exogenous final demand for non-supply constrained sectors.
$\bar{\mathbf{x}}_{\mathbf{co}}$ …	($n-k$)-element column vector of elements x_{k+1} through x_n, representing exogenous total output for supply constrained sectors.

Table (21): Submatrices of Eq. (124).
Adapted from Miller and Blair (1985, p. 332) and Hubacek and Sun (2001, p. 332)

The literature holds a number of interesting applications of the supply-constrained model e.g.: Tiebout (1969), Davis and Salkin (1984), Subramanian and Sadoulet (1990), Parikh and Thorbecke (1996), Hubacek and Sun (2001) and Spörri, Borsuk et al. (2007). All of these studies use the method to incorporate the absolute scarcity of available land in a country. This has been achieved by exogenising the output of the agricultural sector based on available land and assumptions about associated land productivities. In order to measure the potential effects of Peak Oil for an individual economy, one would have to find the sectors that introduce the resource into that economy. The empirical analysis, which follows in this text, uses the two sectors of “petroleum & natural gas extraction” and “petroleum refining” for this purpose.

1.11 Empirical application of the supply-constrained model

After reviewing the methodology, literature and empirical applications of the supply-constrained IO model it has become evident that it is a prime candidate for analysing sudden output reductions of certain sectors. The methodology is sound and straight forward, the literature does not hold any fundamental criticism of the model and empirical applications have produced very useful results. In order to measure the possible effects of Peak Oil we adopt a simplified scenario, assuming that the phenomenon produces an oil supply reduction to the sectors responsible for its extraction and refining. Hence the use of a static model and the assumption of fixed technical coefficients are justified. Moreover, we only consider the national level. This has foremost two implications: Firstly, we do allow oil-imports from or exports to the rest of the world in the economies we study. Secondly, we are not taking embodied oil in imported goods into account. The same is true for imports of crude oil and refined petroleum products, which are then used as inputs for domestic products (other than refined petroleum products), and crude oil embodied in other imported products.

Two sectors were chosen to reflect the constraints experienced by an economy due to Peak Oil: "crude oil and gas extraction" and "petroleum refining'' (referred to as "the oil sectors" in this text). These sectors were subjected to a 10% reduction of total output, which is in the same range as historical reductions of world oil and gas output during past oil shocks: Suez crisis (1956) -10.1%; Arab–Israel war (1973) -7.8%; Iranian Revolution (1978) -8.9%; Iran–Iraq war (1980) -7.2%; Persian Gulf war (1990) -8.8%) (Hamilton 2003). However, the actual percentage of the output reduction is not considered of ultimate importance here. The goal of this study is not to measure the potential extent of damage caused to an economy, when it is facing an oil supply restriction, but to contribute to a deeper understanding of the effects upon the actual economic structure of such an economy. For the same reason we are less interested in the actual magnitude of the caused output reduction, than we are in the rankings of the affected sectors. In any case even if the supply shock was more than 10%, the total sectoral output reduction is bound to be very small, given the oil sectors' minor share of total value added: 2.2% (UK-1995); 0.98% (Japan-2000) and 1.63% (Chile-1996).

IO tables for the United Kingdom, Japan and Chile were chosen for this study, with the intention to include economies that would differ in terms of their endowment of oil and gas resources, i.e. of them being either net-oil exporters or importers. In addition, the disaggregation levels of their IO tables proved to be favourable for our purposes. We used a 1995, 138-sector, UK table; a 2000, 104- sector Japanese table and a 1996, 73-sector Chilean table. All tables are commodity-by-commodity. For those sectors that were intuitively expected to be most affected, no further aggregation was imposed. For the remaining sectors an aggregation to a meaningful level in accordance with the industry classification system was chosen and imposed, using the procedure outlined in Miller and Blair (1985, p. 174). As a consequence, the disaggregation level was reduced to 39, 43 and 40 sectors for the UK, Japan and Chile, respectively.

1.12 Results

According to the rationale of the supply-constrained IO approach, the reduction of 10% of output of the oil sectors is distributed throughout the economy: Firstly, the simulated output change of the supply-constrained sector leads to a decrease in final demand of that sector, which is assumed to be mostly due to an increase in imports, for net-oil importers and a decrease in exports for net-oil exporters (here the UK only). The rationale behind this is that adjustments in household consumption would involve changes of household technologies and lifestyles, which are difficult to achieve in the short-run (changes in the transport system from private cars to public transport, installation of energy saving measures in buildings, etc.); equally, unfinished investment projects must be continued and plans for new investment are not yet accounted for, and adjustments in government consumption are also not possible in the short-run when budgets are committed.

Secondly, it modifies the multiplier matrix, which changes the technology structure and thus oil as a factor input. Other non-constrained sectors will show output reductions due to this change in multipliers and the same is true thirdly due to the backward linkages they maintain with the oil sectors. Table (22) summarizes our findings.

UK 1995

relative sector change	%	absolute sector change	Mill £
Inorganic chemicals	-0.99	Financial intermediation	425.93
Manufacture - Fabricated Metal Prod.	-0.39	Construction	147.21
Coal extraction	-0.23	Manufacture - Fabricated Metal Prod.	89.29
Railway transport	-0.20	Wholesale and Retail Trade	71.42
Construction	-0.17	Manufactoring (other)	67.50
Financial intermediation	-0.15	Ancilliary Transprt, Postal Services, Telecom	54.43
Electricity production & Distribution	-0.14	Electricity production & Distribution	35.38
Manufacture -Iron and Steel	-0.14	Manufacture - Machinery & Applicances	25.48
Air Transport	-0.13	Other land transport	22.05

Ancilliary Transport, Postal Services, Telecom	-0.10	Other services	17.82

Japan 2000

relative sector change	%	absolute sector change	Mill ¥
Water transport	-0.328	Other Services, Office Supplies etc.	23,594.84
Transportation services	-0.140	Financial and Insurance	19,813.29
Electricity	-0.073	Water transport	17,518.26
Coal mining	-0.055	Commerce	12,610.22
Financial and Insurance	-0.051	Transportation services	12,279.94
Reuse and redycling	-0.038	Electricity	12,275.62
Road transport (except by private cars)	-0.025	Education, health and social work	6,565.02
Gas, heat and water supply	-0.023	Communication and broadcasting	4,319.07
Organic chemicals	-0.023	Misc. manufactured products (1/3)	4,161.23
Communication and broadcasting	-0.019	Road transport (except by private cars)	4,078.59

Chile 1996

relative sector change	%	absolute sector change	Mill. Ptas
Road freigth transport services	-0.2513	Real Estate, Business Services & Housing	4,047.63
Metal products	-0.0937	Road freigth transport services	2,926.93
Electric& Non-electric machinery& equmnt	-0.0843	Trade services	1,688.74
Basic chemical products	-0.0831	Misc. Manufactured Prod. (1/2)	1,033.60
Rubber products	-0.0771	Electricity	693.44
Railway transport services	-0.0763	Metal products	627.74
Real Estate, Business Services & Housing	-0.0601	Financial & Insurance services	429.51
Glass and non metallic mineral products	-0.0559	Electric& Non-eclectric machinery& equmnt	374.13
Air transport services	-0.0554	Hotel & Restaurant Services	355.30
Electricity	-0.0501	Glass and non metallic mineral products	353.15

Table (22): The 10 most affected sectors for the UK, Japan and Chile; absolute and relative. The colour code shows a spectrum from dark grey (more affected) to light grey (less affected) in relative terms which is carried over to the absolute values to facilitate comparison.

It shows the 10 most affected sectors for each country in absolute (in the respective currency) and relative terms compared to their original outputs for the 1995-UK, 2000-Japanese and 1996-Chilenien economies. Relative effects are shown because they will be most important for the sector itself in terms of detrimental implications for its continuing profitable operation. Absolute effects, on the other hand, may be significant for the whole economy, as GDP may be reduced substantially. A large percentage decrease of output in a sector that is contributing little to GDP may be less harmful for the whole economy than a small percentage of an "important" sector such as "wholesale and retail trade".

As expected the reduction of endogenous output caused in the non-supply-constrained sectors by the reduction of available oil is rather minor in value terms, both absolute and relative. Relative to total value added (excluding the oil sectors), the UK shows 0.17%, Japan 0.027 and Chile 0.056% additional reduction in output.[102] However, as already mentioned above, it is not so much the magnitude of change itself that is of interest, but to see which sectors are hit more than others when facing a supply restriction of a key resource.

Relatively high impacts can be observed in the following sectors: electricity production, transport, finance/insurance and wholesale/retail. Electricity production is the only sector that shows significant impacts in all three countries both in absolute and in relative terms. Since the sectors' direct backward linkage, to the oil sectors are generally not very strong (e.g. 0 for oil extraction and 0.021 for refining in the UK), this result can probably be attributed to the change of actual factor inputs via modified multipliers. Hence the impact may be due to the electricity sectors' reliance on gas as one of its major direct intermediate inputs in most countries. In Japan it is the sector with the fourth largest decrease in output, while it is on position 7 in the UK and 10 in Chile in relative terms.

Hardly surprising is the relatively strong impact on the different transport sectors given their importance in today's globalised market economy. In Japan water transport is the most affected sector in relative terms and comes third in absolute terms, probably due to the sectors' dependence on overseas oil. Moreover "transport services" and "road transport" are also among the ten most affected sectors in that country. In Chile "road freight transport" is the sector with the highest impacts in relative and the second most in absolute terms. Railway and air transport also feature in the 10 most affected sectors in relative terms. In the UK the most affected transport sectors are the railways at position four, before air transport and "ancillary transport and postal services". The high positions of transport by rail in the UK and Chile and by water in Japan could be attributed to their strong backward linkages to the oil sectors.

The merits of using IO analysis for this study are probably most obvious in the case of the "financial and insurance services" sector, where the extent of the inflicted reduction in output will be almost entirely due to indirect effects. The sector occupies position 6 in the UK and 5 in Japan in relative terms and comes first in the UK, second in Japan and seventh in Chile in absolute terms. Finally three very similar sectors namely "wholesale and retail trade" (UK),

[102] These numbers are not reproduced in Table 16.

"commerce" (Japan) and "trade services" (Chile), all feature among the top four affected sectors in absolute terms, as one would expect given their general importance in modern economies. Although considering this sectors, reliance on transport, one would possibly expect even higher positioning, in particular, in relative terms.

Sectors that were expected to show higher impacts were primary sectors such as agriculture. Although its direct backward linkage will be minor, the reduced factor input caused by changes of the multipliers was expected to be of influence due to its dependence on artificial fertilizers and pesticides, both of which require oil and gas for production. However, surprisingly, even in Chile, where intensive industrial agriculture and fisheries are an important part of the economy (in particular with regard to exports) their combined changes (0.013%) are among the lowest.

Endogenous final demand of the supply-constrained sectors shows rather dramatic relative changes in terms of their original value. Table (23) summarises the respective changes of output and net exports for each country before and after the application of the model. As already mentioned above it is assumed that changes in endogenous final demand for the supply-constrained sectors will be fully met by changes in their net exports (exports - imports).

The differences between the net-oil exporter UK and the net-oil importers Japan and Chile are clearly reflected in Table (23).

		Final Demand (Y) of oil sectors				Net Exports (E^{net})		
		Y_{old} (before)	$Y_{new}^{-10\%}$(after)	$Y_{new} - Y_{old}$	%	before	after	%Δ
UK 95	crude oil & gas ex.	7,630	6,470	1,160	-15	6,200	5,040	-19
Mill. £	petroleum refining	6,640	5,480	1,170	-18	1,700	530	-69
Japan 00	crude oil & gas ex.	-23,500	-197,000	173,500	-738	-7,122,000	-7,295,500	2
Mill. ¥	petroleum refining	4,399,500	3,086,000	1,313,400	-30	-1,563,200	-2,876,600	84
Chile 96	crude oil & gas ex.	500	-1,300	1,800	-377	-536,700	-538,500	0
Mill. Pts	petroleum refining	201,400	119,400	82,000	-41	-294,500	-376,500	28

Table (23): Final demand and net-exports of the "oil sectors" before and after the ten percent supply shock (numbers are rounded)

Relative reductions in final demands are much higher for Japan and Chile than they are for the UK. However, the high percentage change of final demand for crude oil and gas of the net-oil importers (679% Japan, 377% Chile) has to be seen in relation to the fact that for any country deliveries of unrefined oil and gas to final demand are very small. Due to some decreases in stock, Japanese total final demand of crude oil and gas is altogether negative even before the supply shock. The only reason why deliveries are so high in the UK is because of exports. (Recall that final demand Y includes household, investment, government and export demand). Instead of looking at the changes of final demand, it is more revealing to analyse the difference between net exports before and after the supply restriction. Negative figures for net exports on the far right-hand side of Table (23) can be seen as imports, while positive figures are exports. The UK is still a net exporter after the restriction, although its exports of crude oil and gas are reduced by about 20% and exports of refined petroleum by almost 70%. The dramatic reductions of 679% and 377% of final demand for crude oil and gas in Japan and Chile immediately drop to a mere 0,11% and 0.34%, respectively, if seen as an increase of net imports. In terms of refined oil products, however, it becomes evident that Japan will require almost a doubling of its net-imports and Chile an increase by nearly one-third. These are very serious developments, which are bound to change the face of these economies.

1.13 Limitations

The results described above have to be interpreted with caution as several limitations apply. We are aware that we used a static model for a process that is inherently dynamic. However, the purpose of this research was not so much to deliver final quantitative results, but to assess the effects of a sudden shock and its ripple effects throughout the economy during a short time period. For this type of analysis the systems approach of IO analysis (even if static) is very suitable.

Moreover, a further simplification, as already mentioned, is that we did allow imports to increase. If imports were restricted, then the reduction in total final demand would have to be absorbed by all of the different final consumers, either according to their original share, or on the bases of some externally determined preferences (compare Hubacek and Sun 2001). Thus one may, for example, argue that oil for heating homes should receive priority over government use of fuel for military purposes. In other words the government could impose some kind of rationing system. If this were not sufficient or not adequate, such a rationing system would have to look at reducing intermediate demand. According to certain criteria, some industries could again be given preference in receiving their share of oil and gas supply. Hubacek and Sun (2001) in their study applying supply constraints on land have, for example, prioritised sectors according to their creation of value added per unit of land (land allocation according to highest and best use). This strategy favoured the labour intensive service sectors, which received their land share first.

This simplification also implies that we ignore the international perspective of Peak Oil by only looking at one region at a time. Moreover, ripple effects throughout the world economy affecting production and consumption of other countries and thus the import prices and exports of the country under investigation, are not considered. For example, reductions in outputs in the oil sectors of one country would have effects on production of exports for this country to other regions. Thus, a single country approach is likely to underestimate the overall effects. The application of a multiregional or World IO model could address this limitation but would be very data intensive. However, for future studies this is certainly a matter of interest, and in fact, a number of ongoing studies working on developing global IO models (Duchin 2005; Giljum and Lutter 2008).

Finally, this study only covers the quantity dimension of the Peak-Oil phenomenon. The authors are aware that there is also a price dimension, which shall be addressed, using the Leontief price model, in future studies. As already mentioned this paper is to be understood as a first venture into this very important topic using the IO framework.

1.14 Conclusion

As it was argued above, there is an urgent need for the development of methods and models to analyse the possible implications of Peak Oil in particular and resource supply disruptions in general. The input–output framework provides a good base for this purpose. It has long established and refined methods based on real world data provided from most statistical offices which allows for cross-sectional analysis and comparability across countries. However, as one of the assumptions of the demand-driven Leontief model is that supply is perfectly elastic for every input, it is unsuitable for analysing supply constraints. The review of two alternatives showed that the intuitively most attractive supply-driven model is based on very restrictive assumptions. This is unfortunate since it seems perfectly rational to make the industries output dependent on the output of the oil sectors, considering the dependency of world economies on oil and gas.

The supply-constrained or mixed model on the other hand has much more favourable properties. It has been demonstrated that it is a highly promising candidate for analysing the quantity dimension of Peak Oil, which is why it was chosen for a first cautious empirical analysis in this study. Despite the limitations of this first application, there are already some very interesting insights to be gained. The study already allows some conclusions as to which sectors are the most vulnerable to oil supply constraints in the studied countries. For example, while one would expect to find the transport sectors to be highly affected it is very interesting to see the high ranking of the "finance and insurance" sector, whose links with the oil sectors are less visible.

Input–output analysis has frequently been criticised for its constant production coefficients. But this is rather a virtue in the context of this study. Production technologies cannot be replaced instantaneously and thus fixed coefficients allow the evaluation of short-run effects of supply shocks, damages through environmental events or other human-made catastrophes. Thus IO has proven to be very valuable for risk assessments as performed in this study.

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1.16 References

Please note references of this article have been integrated in the bibliography of Part 2.

2 PAPER II

Economic vulnerability to Peak Oil[103]

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2.1 Abstract

In recent years worries of a possible imminent decline of global oil production levels, known as Peak-Oil, have evolved from a minority view of some oil industry insiders to a prominent debate. Little is known about what the "end of cheap oil" could mean for economies at the sector level. In this research effort we draw a three-dimensional analytical vulnerability map of the U.S. economy (world's largest oil consumer). Two of these dimensions indicate relative sector importance, one monetarily and one structurally. We use forward linkages from Input-output analysis (IOA) to measure a sector's direct and indirect contribution to GDP and social network analysis (SNA) to measure the total number of other sectors to which a given sector provides inputs, independent of quantity and value. The third dimension on the other hand is our indicator for sector-level vulnerability to Peak-Oil. We use the price model (PM) from IOA to calculate the expected direct and indirect sectorial price increases, caused by a 100% oil price increase. We argue that this map can be used to identify sectors and groups of sectors which, because of their position, may render the entire economy vulnerable to Peak-Oil. These include metals and metals processing, petrochemicals and derivatives (e.g. plastics) and transport services (in particular air transport). As the case of plastic packaging illustrates, for many vulnerable and important sectors, it may be difficult to find substitutes, as possible candidates (e.g. paper, cardboard or alloy packaging) show similar or higher levels of vulnerability and importance. In our view, such analysis is key for designing adaptive policy measures in the face of increasing scarcity of oil.

[103] This paper is in the process of being submitted very shortly, subject to adaptations and formatting according to the standards of the respective journal. It is available from the authors upon request.

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2.2 Keywords

price model, social network analysis; outdegree; input-output analysis; forward linkage; peak oil; vulnerability; relative sector importance

2.3 Introduction

Peak Oil refers to the point in time when, as a global society, we will have reached the maximum rate possible for petroleum extraction. After this point, demand for oil will begin outstripping supply, the oil supply will never return to its former rate, and extraction will become ever more difficult and expensive (Hubbert 1956; Campbell and Laherrere 1998; Aleklett and Campbell 2003; Aleklett 2012)[104]. The debate between those who argue that this point is near or passed already (Aleklett, Höök et al. 2010; Kerr 2011; Aleklett 2012; Hamilton 2012; Kerr 2012; Murray and King 2012; Sorrell 2012) and those who believe we still have enough oil to "fry us all" (Yergin 2011; Yergin 2011; Maugeri 2012; Monbiot 2012), is far from settled. However, there has been a steady increase in concerns from renowned and independent[105] scientists and analysts regarding the possible dangers of Peak-Oil (Hirsch 2005; Sorrell, Speirs et al. 2010; USJFC 2010; ZTransfBw 2010; Hall and Klitgaard 2011; Helman 2011; Hirsch 2012; Meadows 2012), or (in settings where the use of the concept Peak-Oil is avoided) of an imminent energy supply crunch (Birol 2008; MacAlister and Monbiot 2008; Connor 2009). Taken together, the prediction of uninterrupted fossil fuel flows for many decades to come (Jackson 2006; Jackson 2009; Maugeri 2012) is an increasingly isolated view among experts.

In recent years, the concept of "resource peaks" has found its way into the analysis of other key resources for the human economy. The scientific and popular literature now talks of Peak-Coal (Zittel and Schindler 2007b; Hughes 2008; Kerr 2009), Peak-Phosphorus (Déry and Anderson 2007; Cordell, Drangert et al. 2009), Peak-Uranium (Dittmar 2011; Dittmar 2012), Peak-Minerals (Bardi and Pagani 2007; Mason, Prior et al. 2011), Peak-Water

[104] The term and concept of „peak oil" were invented by Collin Campbell and Aleklett Kjell, when the founded ASPO (the Association for the Study of Peak Oil) in 2002. The Word order is due to the anecdotal fact that they did not like the sound of the acronym ASOP (Aleklett 2012).

[105] Governmental and Intergovernmental Organizations such as the USGS (United States Geologic Survey), EIA (Energy Information Agency) or the IEA (International Energy Agency) are criticized for publishing overly optimistic numbers (Bentley 2002; Hirsch 2005; Jakobsson, Söderbergh et al. 2009; Aleklett, Höök et al. 2010; Gail the Actuary 2010; Gail the Actuary 2011) to please their clients (MacAlister 2009; Badal 2010). Similar criticism is voiced over the most outspoken non-governmental authors arguing against an imminent peak of global oil production. Daniel Yergin from CERA (Cambridge Energy Research Analysts) and recently Leonardo Maugeri associate of the Harvard Kennedy School and employed by ENI, are criticises for their close links to the Oil industry, which still largely rejects the concept of Peak-Oil (with the exception of TOTAL).

(Vaughan 2009; Gleick and Palaniappan 2010), …, Peak-Everything (Heinberg 2007). As phenomenon, concept or metaphor, these 'resource peaks', discussions carry an important message; in particular, they shift attention away from the notion of 'depletion' to a regime shift in our energy system.

For example, the fact that there may be as much oil in Canadian tar sands, as there is in Saudi Arabia's underground supplies, does not mean that the former can simply replace the latter. There is a fundamental difference in quality between these two sources and their daily possible production rates. The latter is referred to as the size of the "tap" and is an essential variable of the Peak-Oil phenomenon, which is essentially not a "stock" but a "flow-problem". The lower quality implies higher costs of extraction and processing and lower flow-quantities in higher prices due to supply shortages. Hence peak phenomena could best be summarized as "the end of cheap resources" and the resulting economic (and societal) consequences, which is the before mentioned regime shift.

The most extensive and rigorous meta-analysis of "below ground" Peak-Oil studies and evidences so far was undertaken by Steve Sorrel and his associates from UKERC (Sorrell, Speirs et al. 2009). The authors concluded that a production peak of conventional oil before 2030 for below ground (i.e. geological) reasons (as compared to 'above ground' reasons: geopolitical, economic and social) was likely and that there was a significant risk for this to occur before 2020. Un-conventional oil has not been taken into account in the report, it argues however that production from such sources (e.g. Canadian Tar Sands) is unlikely to expand enough to fill the gap because of their before mentioned limitations. Moreover, their extraction appears environmentally and socially problematic (Kean 2009). Similar problems and limitations are emerging regarding the recent boom of shale oil and gas (Strahan 2007; Berman 2012; Healy 2012; Mearns 2012; Reuters 2012), which had motivated the IEA to herald the start of a 'golden age of gas'.

Nevertheless the point of this paper is not to enter into the details of the debate about the exact timing of Peak-Oil. Instead we argue that the available literature suggests that there is a significant risk that it either has occurred already or is about to occur soon. Reason enough for us to ask the question of what could happen to our economies and how vulnerable are they to Peak-Oil. Compared to the large amount of 'below ground' debate, research and literature 'above ground' analysis addressing the above questions are still rare (exceptions include Arto-

Oliazola and Kerschner 2009; Kerschner and Hubacek 2009; Logar and van den Bergh 2011; Lutz, Lehr et al. 2012). In general, economists have shown little interest in investigating the effects of oil price shocks. For a review of the existing literature see Hamilton (2005); and Kilian (2008).

According to mainstream economic theory impacts of such oil-price shocks can only be rather minimal and temporal, because they tend to argue that oil (as any resource) is only scarce in a relative sense (e.g. Barnett and Morse 1963; Solow 1974; Lenssen and Flavin 1996; Adelman and Lynch 1997; Lynch 1999; Odell 1999; Hisschemoller, Bode et al. 2006; Jackson 2006; Maack and Skulason 2006), not absolutely (Daly 1992). This means that price mechanisms on free markets are supposed to raise the price of one resource, making it attractive to explore substitutes or to develop technologies for using it more efficiently i.e. the so-called Hotelling's Rule of 'substitutability' (Hotelling 1931) or Nordhaus et al.'s 'backstop technology' (Nordhaus, Houthakker et al. 1973). Although we do not dismiss this line of reasoning, we think it to be more likely that when oil supplies run low, there will be sharp fluctuations in energy prices; similar to or even exceeding the ones experienced in 1973, 1979, 1990, and most recently in 2008, when oil climbed over 140 US dollars per barrel. Similar price spikes can be expected for the near future some analysts say (Pickrell 2012). Such sharp increases, can act as 'shocks' to the economic system, in that much of the economy would be affected, simultaneously and suddenly, due to the wide use of oil and petroleum-based products.

This idea that increases in oil prices can jolt the economic system is nothing new: the "Hirsch-Report" (Hirsch 2005), which was commissioned by the U.S. Department of Energy, concluded that Peak-Oil will cause an energy crisis never seen before; oil prices will dramatically increase, thus causing prolonged economic hardship. In addition, the report predicts that economic recovery will require, at a minimum, "a decade of intense, expensive effort" (p.5), due mainly to there being a 100 trillion US dollar infrastructure installed worldwide, which runs exclusively on oil (Hirsch 2012). These concerns are echoed by the US Pentagon, which is the world's largest single consumer of oil: "By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 million barrels per day" (USJFC 2010, p 29). Similar warnings were issued in a study by the center for transformation of the German Bundeswehr (ZTransfBw

2010). Hardly surprising then, that the US armed forces have been preparing for resource wars already some time ago (Scheer 2005; Clonan 2008).

Others, however, see economic hardship due to oil supplies as already occurring (Scheer 2007); experts have begun arguing that high oil prices due to supply limitations (Murphy and Balogh 2009; Theramus 2009; Lewis 2010; Chanel 2012), or other reasons (Hamilton 2009; Kaufmann, Gonzalez et al. 2010) may have been partially responsible for the world-wide financial crisis of 2008. In addition, some believe that the current recession in many OECD countries and the EURO-crises are directly or indirectly caused by overheated and volatile oil markets (Hagens 2008; Stern 2010; Tverberg 2010; Skrebowski 2011; Li 2012). Officials within the International Energy Agency (IEA) also have been growing increasingly nervous about an imminent energy crisis (Birol 2008; MacAlister and Monbiot 2008; Connor 2009). However, according to a whistleblower within that agency, the IEA is under pressure from the US administration to varnish its numbers, i.e. to disguise an apparently growing gap between potential production and consumption forecasts (MacAlister 2009; Badal 2010). Finally, business groups in the UK have begun organizing themselves to address the potential consequences of peak oil: the Industry Taskforce on Peak Oil and Energy Security (ITPOES)[106], a lobby group consisting of multiple UK based companies and firms (including Virgin Media, for example), continually lobbies the UK government to address the issue of peak oil (ITPOES 2010). Taken together, there is clearly a growing concern that constrained oil supplies can, and may already have, negatively affected the economy, both in the US and worldwide.

2.4 Relative sector importance, resilience and economic vulnerability

Oil is a “risky resource”, in that it is non-renewable, and given Peak Oil concerns, it is seen unwise for any economy to be highly dependent upon it (Hagens 2008; Hopkins 2008). Such resource dependency, according to Adger (2000), reduces the *resilience* of a system and makes it *vulnerable* to hazardous events (Adger 2000; Adger 2006). By resilience, we mean "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker 2004, p. 1). *Vulnerability* refers to the weaknesses of a system, due an overdependence on a particular resource, the system’s structuring, or a combination of the two. Vulnerability thus reduces a system’s resilience (Turner, Kasperson et al. 2003). In the case of our present

[106] http://peakoiltaskforce.net/

study, we see Peak Oil as an exogenous shock to the economic system, and we see the economy's dependence on oil as a vulnerability hat reduces the system's resilience in terms of its adaptability and transformability (Walker, Holling et al. 2004; Rockström, Steffen et al. 2009). It reduces the economy's ability to adapt to, cope with and recover from the impacts of constrained oil supplies.

According to the resilience literature, the correct response to such as situation is adaptive resource management (WCED 1987; Brandis 1989), a first step of which is to gain a better understanding of the properties of a system and its resource dependency (Folke, Carpenter et al. 2002; Walker, Carpenter et al. 2002; Turner, Kasperson et al. 2003; Walker 2004; Adger 2006; Gallopín 2006). Developing such an understanding can inform policy: for example, policies may need to include supporting or sustaining certain key economic sectors, while restraining others. Other policy approaches may favor the phasing out or substitution of sectors, which are both vulnerable to Peak-Oil and important for the economic system. Providing a tool for identification of such sectors is the goal of this paper.

2.5 Method

For the purpose of this study, we distinguish vulnerability at two different scales: one being the entire economic system (the macro level), and the other being the individual sector of an economy (the micro level). In order to arrive at an indicator for macroeconomic vulnerability we propose a case-study approach by looking at U.S economic data. The question we ask ourselves are twofold: i) which sectors are potentially most affected by and therefore vulnerable to Peak Oil; and ii) which of these sectors are most important to the U.S. economy? The underlying idea is that if both conditions hold true for a considerable number of sectors, the entire macroeconomic system can be considered vulnerable to Peak-Oil according to our analysis. We use the expected increase of a sectors' output, after an assumed escalation of oil prices (be it for below or above ground reasons) as a proxy for a micro-level vulnerability to Peak-Oil. The Leontief input-output price model is employed to reveal these potential price increases. However, this approach does not tell us the relative importance of these sectors. Thus, we need measures to identify whether a vulnerable sector is also one important to the macro-economy. Towards this end, we make use of two other analytical measures: one being *forward linkage analysis* (FWLA) from Input-Output analysis (IOA) (see e.g.Miller and Blair 2009), which considers the direct and indirect contribution of a sector to GDP, and the other being *outdegree centrality* from social network analysis (SNA), which counts how many direct links a sector has with other sectors, thus providing an indication for how embedded a sector is within the overall economy. As such, these two measures emphasize slightly different aspects of sector 'importance', one for "money" and one for "structure".

Although Peak Oil is a global phenomenon, the U.S. Economy is a warranted case study; the country is the largest economy and the biggest consumer of oil and oil-based products by a wide margin, and as such, can act as a worthy example of what an economy highly dependent on oil looks like, and thus, how dependency can translate into systemic-wide vulnerability in the context of Peak Oil. Note that our definition of vulnerability and importance is based on the structure and functioning of the current economic system, which is not a trivial fact. The resilience literature today emphasizes that the focus of policy makers needs to be on facilitating the capacity of systems to use the impetus of external shocks in order to adapt and transform, rather than to resist them and remain unchanged (e.g. Ricardo 1821)

2.5.1 The Price Model (PM)

Kerschner, Bermejo et al. (2010) already argued that the effects of oil price shocks were difficult to model, but best suited were sectorially disaggregated economic models. Moreover input-output analysis, which is modelling at the sector level, has been identified by Kerschner (2006) and Kerschner and Hubacek (2009) as a useful approach for estimating potential economic effects of Peak-Oil. They used a supply constrained quantity model, which they applied to data for the UK, Japan and Chile. Kerschner (2006) also identified the Leontief Price Model as a promising candidate for analysing the price dimension of Peak-Oil and the same authors (2007; 2012) then applied the model to the UK, Japan and China[107]. Previously applications focused mainly on simulating the price impacts of environmental policies (Giarratani 1974) , fuel (Catsambas 1982) and other taxes (Melvin 1979; Hughes 1986; Manresa, Polo et al. 1988; Cardenete and Sancho 2002), or more general changes in primary inputs and import prices (McKean and Taylor 1991; Llop and Manresa 2004).

The Leontief Price Model, also known as cost-push input-output price model (Oosterhaven 1996; Dietzenbacher 1997), is the mathematical dual of the traditional demand-pull input-

[107] Logar and van den Bergh (unpublished), repeated the application of the Price model to a Peak-Oil scenario for Spain, adding an impact analysis for the Spanish Tourism sector. They observed the highest price changes in the energy, mining and transport sectors but also – more surprisingly - considerable changes in the chemical and fishing industry.

output quantity model (or Leontief Model)(Miller and Blair 2009). It is also subject to the usual limitations of input-output modelling: fixed input coefficients and constant returns to scale. This also implies that a price increase does not allow for substitution possibilities. However, oil, as a primary source of energy with an extraordinary high net energy content (Odum and Odum 2001; Brown, Cohen et al. 2009) or energy return on investment (EROI) (Hall and Klitgaard 2011), is difficult to substitute in the quantities and qualities needed (Kerschner, Bermejo et al. 2010). Moreover, in this paper, we are interested in the short-term economic effects of Peak-Oil. In this case the Leontief price model provides a reasonable estimation of prices, as in the short-run there is little time for adaptive substitution efforts. Moreover, the model does not take into account final demand changes due to consumer behaviour. Mathematically the Leontief price model can be derived as follows:

(125) $$x_j = \sum_i^n z_{ij} + v_j^l + v_j^k + v_j^m$$

Where x_j is the total input of sector j; z_{ij} is the input of sector i to sector j; v_j^l is labor input in sector j; v_j^k is the capital input; v_j^m is the import. In matrix notion, we re-write equation1 by:

(126) $$x' = i'Z + v'$$

Here, x' denotes a row vector of sectorial inputs; Z denotes an inter-industry matrix of z_{ij}; v' is row vector of sum of labor cost (l), capital (k) and import (m); i' is a row vector of ones.

Substituting $Z = A\hat{x}$ and postmultiplying by $\hat{x}^{-1}$, we can obtain:

(127) $$i' = i'A + v'_c$$

Where A denotes a matrix of technical coefficients that represent the inputs from sectors to produce one US$ worth of output of each sector. v'_c is a row vector of factor input coefficients that denotes the factors of production (capital, labour and imports) required to produce one US$ worth of domestic sectorial output. Hence we can interpret them as base year index prices $\tilde{p}_j$, so that $\tilde{p}' = [\tilde{p}_1, \tilde{p}_2, \ldots, \tilde{p}_n]$. The price model can therefore be defined as follows:

(128) $$\tilde{p}' = \tilde{p}'A + v'_c$$

Which leads to:

(129) $$\tilde{p}' = v'_c(I - A)^{-1}$$

Frequently, the model is transposed and expressed in terms of column vectors rather than row vectors, then

(130) $$\tilde{p} = (I - A')^{-1}v_c$$

Therefore, changes in v_c would lead to both a direct and an indirect price increase in the whole economy due to the interdependency of economic sectors. The price change can be captured by:

(131) $$\Delta\tilde{p} = (I - A')^{-1}\Delta v_c$$

See Miller and Blair (2009, page 43 – 44) for a detailed description of the price model (Miller and Blair 2009).

In this paper, we apply the Leontief price model to US economic data to simulate a Peak-Oil-induced 100% oil price increase. How exactly oil markets will react, once it is clear that peak oil has been reached, is unclear of course. Some have already claimed that we are passed or close to this point and official statistical numbers are said to be intentionally distorted, precisely in order not to scare markets (MacAlister 2009; Badal 2010). Even though projections of future oil prices by official statistical bodies, such as the IEA (International Energy Agency) or the EIA (Energy Information Administration) are continuously revised upwards, their numbers seem still quite low. In 2011 the EIA for example predicted oil prices of 126.03US$ per barrel for 2035 (EIA 2011), while in 2012 this estimate was already raised to 144.98 for the reference scenario (EIA 2012) (the IEA 2012 provides similar numbers). Nevertheless many energy and petroleum analysts doubt the credibility of these projections, as they are based on overly optimistic future production scenarios (Bentley 2002; Hirsch 2005; Jakobsson, Söderbergh et al. 2009; Aleklett, Höök et al. 2010; Gail the Actuary 2010;

Gail the Actuary 2011). A recent report by Barclays for instance predicted oil prices of 180 US$ per barrel until the end of the decade.

Historically, inflation adjusted world oil prices from the turn of the 19th century oscillated between 20 and 40US$, except for the geopolitically motivated price explosions in the 1970ies and 1980ies (Yom Kippur War and Iranian Revolution) and a temporal spike in the early 1990ies (BP 2012). However in 2004, and without any obvious geopolitical driver, world oil prices left this margin for good so far (see Figure 34). They rose dramatically until reaching an unprecedented global record level of 145.16 US$/barrel (Cushing, OK WTI Spot Price FOB) on the 14th of July 2008 (EIA 2012), then briefly collapsing towards 60 US$ during the 2008-2009 world economic recession, only to rise again and remain above 80 US$ until today. Many say that this is already due to the inability of supply to keep up with demand (Hamilton 2009; Hamilton 2011; Kerr 2011; Rapier 2012), an indicator that Peak-Oil may have been reached or is near. Even Faith Birol, chief economist of the otherwise rather optimistic IEA, warns today that high oil prices are here to stay (Tverberg 2012).

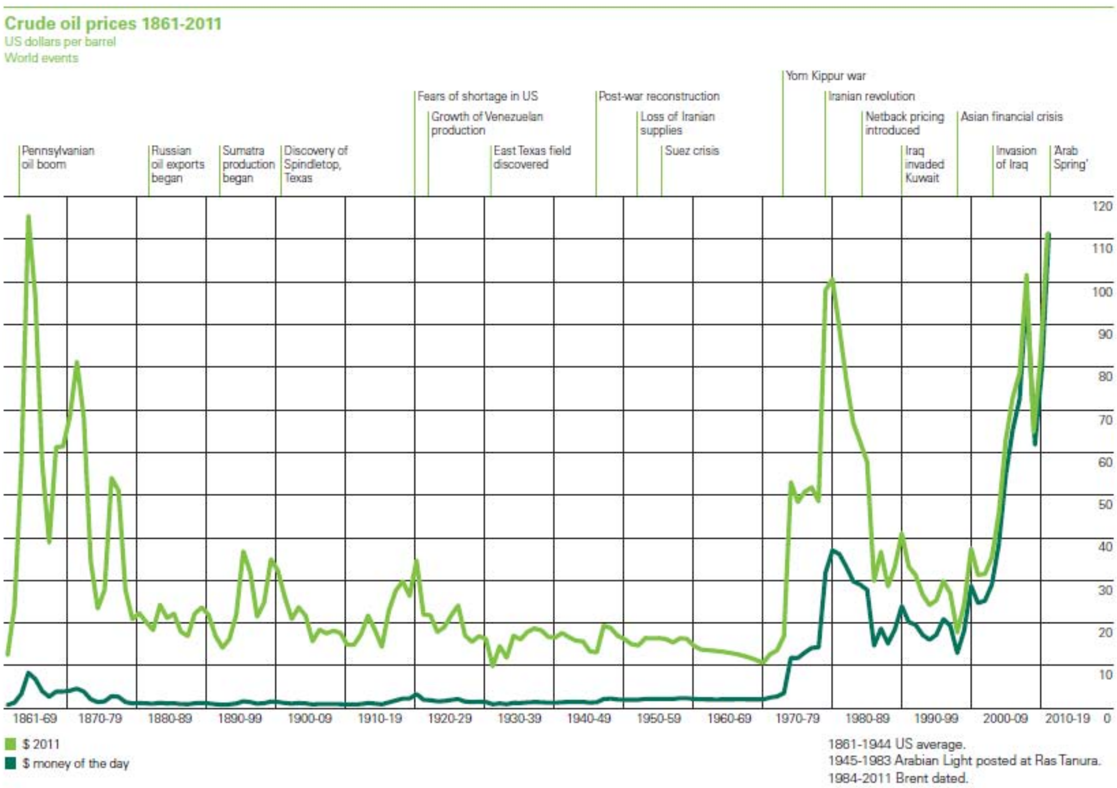

Figure 34: Historic oil prices nominal and inflation adjusted
Source: BP Statistical Review of World Energy 2012

Given these historic price developments we consider a 100% price increase a reasonable market reaction and well suited scenario for simulating economic impacts of oil scarcities due to supply limitations provoked by Peak Oil. Since current (summer 2012) oil prices are just below 100US$/barrel (WTI cushing spot), this would mean a crude oil price of approximately 200 US$/barrel and in fact corresponds to the EIA's (2012) high oil price scenario. (Natural gas prices also double in this simulation, which is justified for the reasons mentioned above.)

The model calculates direct and indirect price increases in all sectors due to a Peak-Oil induced price increase in the "oil sectors". As already mentioned, we use sectorial price increases as a proxy for the vulnerability of the US economy at the sector level. If production prices/costs of an industry rise substantially, one can assume that, depending on the price elasticity of its products, demand will suffer, potentially leading to bankruptcies and the eventual decline of oil thirsty industries. A real world example of today may be the current wave of bankruptcies of German container shipping companies. One of the many other problems this industry is facing (reduced demand due to the global recession, overinvestment and indebtedness, liquidity crises, etc.), are rising fuel prices. Because of the considerable competition in that sector, these companies are unable to pass on these costs to their customers and the rising oil prices eat up their already slim margins (Evans-Pritchard 2012).

For our Peak Oil simulation we followed a dual strategy: First we choose the sector "oil and gas extraction" for representing the 100% price increase of domestically produced and processed oil and gas. Note, that in the Peak-Oil literature Peak-Oil and Peak-Gas are generally mentioned in the same breath (e.g. Aleklett and Campbell 2003), because they are such close substitutes. This is confirmed by empirical studies, many of which suggest an increase in gas prices of about 0.8$ for every dollar price increase in petroleum (Vücel and Guo 1994; Villar and Joutz 2006; Panagiotidis and Rutledge 2007). In order to obtain a 100% price increase of the "oil and gas extraction" sector's output we raised its production costs (factors of production) capital, labour and imports at equal shares by a factor of five approximately (495%). The rationale behind using all three payment sectors at equal shares is that it is beyond the scope of this analysis to investigate which factor of production will benefit in what proportion from the higher prices. It could be the resource owners via higher royalties, the processing industry with higher profits, or the workers with higher wages. Alternatively the higher prices could also simply be due to higher costs in extraction and processing, given the fact that oil today is situated in ever more difficult deposits in ever worse quality.

This can be deducted from the IEA's latest World Energy Outlook (IEA 2012), which clearly shows a current peak or plateau of already producing conventional oil wells plus their shortly expected decline (see Figure 35) Given the 'best-first principle', which has been known in economic theory since David Ricardo (1821), we can assume that those sources, which are supposed to substitute that decline in liquid fuels i.e. oil from yet to be found/developed deposits, unconventional oil[108] and NGLs, are more costly to produce.

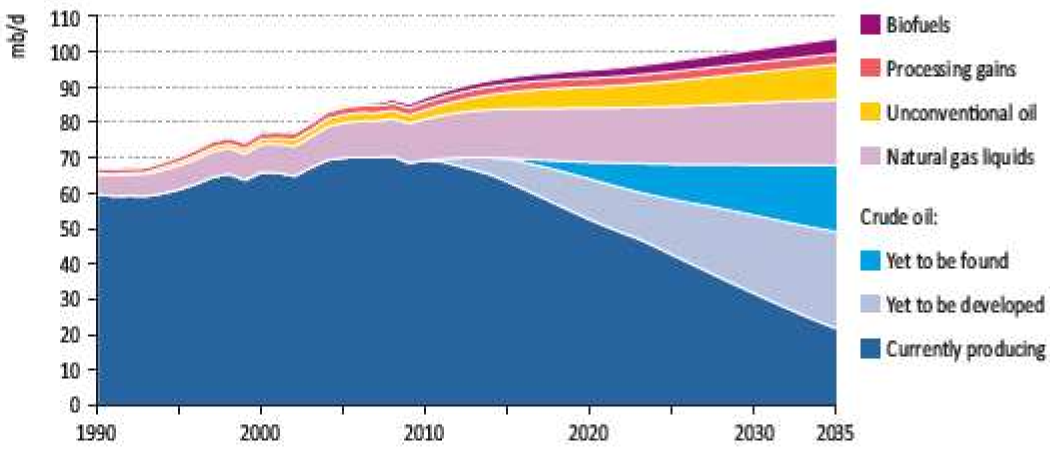

Figure 35: World liquid fuels supply by type in the New Policies Scenario
Source: IEA WEO (2011)

Secondly, we address direct oil and gas imports by all other sectors by increasing the corresponding value of their total imports equally by 100%. Moreover we take an 85% share of all sector's direct imports of refined petroleum products, which corresponds to that sectors fraction of production costs, which is determined by crude oil (the rest are the costs of the refining process)[109] and also raise them by 100%. Here we draw the boundary for our analysis in that we do not consider the inevitable (given world oil markets) price increases in all other imports. Hence our results could be regarded as conservative. Domestic price increases in all other sectors of domestic production e.g. energy production, on the other hand will be taken care of by the ripple effects of the model.

[108] Unconventional oil includes heavy oils, like Canadian tar sands and oil shales, polar and deepwater (> 500m) oil. Very often, NGL's are also included, which are light hydrocarbons that exist in liquid form underground and that are produced together with natural gas and recovered in separation facilities or processing plants e.g. propane and butane.
[109] We generated this number using data of the EIA, regarding the composition of retail gasoline prices (http://www.eia.gov/petroleum/gasdiesel/).

2.5.2 Forward Linkage Analysis (FWLA)

Forward-Linkages analysis (FLA) is one approach commonly used to measure the importance of economic sectors and their economic 'connectedness'. The approach is considered 'supply-driven' in that it looks at all the direct and indirect sales from a sector to see how these contribute to the economy's total output. For example, increased output in sector *j* also means that additional amounts of product *j* are available to be used as inputs in other sectors for their own production. This means that one additional unit of output from sector *j* creates additional revenues throughout the economy, as it is processed by other sectors, increasing their output, which in turn will be used by again other sectors and so on. The term forward linkage is used to indicate this kind of interconnection of a particular sector with those ("downstream") sectors to which it sells its output. To compute forward linkages, one transforms the inter-industry matrix Z (see price model) into a direct-output coefficients matrix (that we call **B**), where each of the coefficients b_{ij} in matrix **B** are calculated as follows:

(132) $$b_{ij} = \frac{z_{ij}}{x_i}$$

Where x_i is the total output of sector i.

Then, allowing for **I** to be the identity matrix, we can generate the inverse output matrix, the so called Ghosh inverse matrix, as follows: $\mathbf{G} = (\mathbf{I}-\mathbf{B})^{-1}$(Miller and Blair 2009). In essence, this inverse matrix is conceptually similar to the idea of multiplying **B** by itself an indefinite number of times, thus resulting in all the direct and indirect flows being captured in one single matrix $G = [g_{ij}]$. Calculating forward-linkages for sector i ($\mathbf{FL_i}$) is straightforward after this initial matrix conversion: one simply takes the row sums of **G**, and each row sum thus reveals the total value of intermediate sales of sector i as a proportion of the value of i's total output. Thus, forward-linkages are calculated as follows:

(133) $$FL_i = \sum_{j=1}^{n} g_{ij}$$

This calculation was done for all 428 sectors in our dataset. The results were then ranked from high to low.

2.5.3 Outdegree centrality from social network analysis (SNA)

Outdegree centrality is a technique from social network analysis (SNA), a methodological approach with roots in sociology (Prell, 2012). Social network analysis is used to analyze social relations such as friendship or acquaintanceship among a given set of actors (often referred to as nodes). Similar to input-output analysis, which organizes economic data as a sector-by-sector matrix, SNA organizes relations into a square, actor-by-actor matrix. Also similar to IOA, social network analysis makes use of matrix algebra for studying structural regularities, and consequently has developed, over time, a tool-kit of concepts and measures for identifying (among other things) important actors according to their structural position in the network of relations.

For the current paper, we made use of outdegree centrality, which is a measure of importance for actors, according to the number of direct, outgoing ties an actor has with others. In the context of our current data set, outdegree centrality would reflect the number of sectors to whom a given sector *i* provides monetary inputs. For example, if the sector 'transportation' had a high outdegree, this would imply that transportation provides inputs to many other economic sectors. As such, it would be considered an important sector.

Computing outdegree centrality first requires a transformation of a given weighted matrix into a binary one. However, determining the cut-off value for transforming the matrix to 1s and 0s is not straightforward: previous uses of SNA for input-output data typically use cut-off values that result in binary matrices consisting of 'important flows' (e.g. Heinberg 2004; Kunstler 2005). Thus, the analyst focuses attention only on those sector flows greater than a specified value, and ignore all others. For our paper, the cut-off value used was simply any value greater than 0. Treating the data in this way enabled us to identify how *all* sectors are connected to one another, not just sectors connected via higher dollar amounts. Thus, we ignored monetary considerations and instead treated all flows between sectors equally. In addition, we chose to ignore the diagonal in our input-output matrix, as we were not interested in observing whether or not sectors gave money to themselves (i.e. self-reflexive loops), but rather, the extent to which other sectors were dependent on (in this case) oil for inputs

Thus, on the dichotomized matrix, we computed out-degree centrality (C_i) for sector *i* as follows:

(134) $$C_i = \sum_{j=1}^{n} x_{ij}$$

Computing outdegree centrality scores for all sectors resulted in another ranking of sectors. A total of 222 ranks resulted, as many sectors held the same outdegree centrality score (see SI for full listing). Again, we thus converted all ranks to percentiles to show in which percentile a given sector rested, based on their outdegree score.

2.6 Results and Discussion

Figure 36 synthesises the findings of our three models. It shows "monetary sector importance" (from FWLA) on the X axis and "relative structural sector importance" on the Y axis (from SNA). The bubbles (circles) represent sectors, some of which carry sector numbers for illustrative purposes (See Appendix I for a full list of sectors, numbers and results for all three models.). Very high "FWLA levels", i.e. direct and indirect output contributions to GDP, can be observed for forest nurseries & products (sector 15), iron ore mining (22), logging (16) or Alumina refining (172) for example. In terms of structure (i.e. outdegree centrality), the most important sectors are clearly transport and transport related sectors e.g. pipeline or air transportation (327 & 326) and car washes (406). Moreover we have colour-coded primary sectors in red (agriculture, mining, etc.), secondary (manufacturing) sectors in blue and tertiary (service) sectors in yellow. Through color-coding economic sectors (e.g. primary, secondary and tertiary sectors), we can see how these sector categories tend to be grouped together, primary sectors rather on top and bottom left, secondary in the centre and tertiary at the bottom left and centre far right. The size of the bubbles visualizes the vulnerability of a particular sector to Peak-Oil according to the expected price changes (from the PM). Highest sector-level vulnerabilities therefore are expressed by carbon black and fertilizer manufacturing (124 & 130), the petrochemical industry (120), Fishing (17) and pipeline and air transportation (327 & 326).

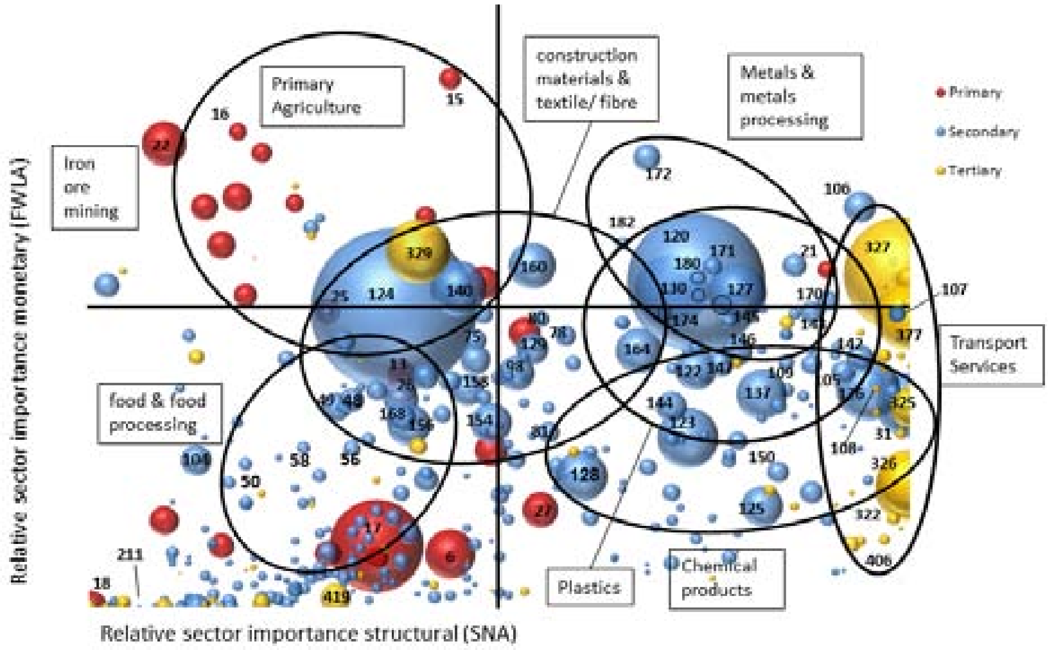

Figure 36: Sectorial importance and vulnerability to peak oil.
Note: red bubbles represent primary sector; blue bubbles represent secondary sectors; yellow bubbles represent tertiary sectors. The size of bubble reflects sectoral price change due to peak oil.

We further divide the graph in 4 quadrants. In quadrant 1 we can identify less important sectors in terms of both “money” and “structure”. As we can see there is a large number of these sectors at the bottom of this part of the graph, extreme examples being hunting & trapping (18) or optical instruments and lenses (211). Moreover, there is a cluster of larger bubbles, which could be summarized as “food production and processing”, with sectors such as sugar production from beat or cane (48, 49), flour milling (43) or cheese production (56). These sectors show considerable price increases - in particular the sugar sectors 48 and 49. Just on the border of this cluster is the fishing industry (17), which is worth mentioning, as it is the primary sector with the highest price increases of all. However, the relatively small monetary and structural importance of sectors in this quadrant suggests that “Peak-Oil policy action” may be less urgent, except for facilitating their role as substitutes to sectors in quadrant 3, as we will elaborate below. Note that our definition of “sectorial importance”, refers to the importance of a sector according to our categories and from the perspective of today’s economic system. In a post-carbon economy (i.e. a different economic system), their role and that of other sectors in this quadrant might easily change.

Moving to quadrant 2 of Figure 36 means increasing the monetary importance of the contribution of a particular sector to GDP (in this case of the US). We note immediately the presence of a large number of primary sectors in this quadrant, in particular of agriculture (e.g.: tobacco, sugar cane or oil seed farming; cattle ranching or other animal food production). It is not surprising that these sectors are structurally less important as their products tend to enter mostly into the respective processing industries e.g. iron ore mining (22) into iron mills (170) and agricultural products into food processing industries.

As this very example shows, that next step on the production chain can be extremely important structurally (find sector 170 at the bottom extreme right of quadrant 3). Same is true for carbon black (124) as the main ingredient to tire manufacturing (150) and logging (16) plus pulp mills (104) providing the raw material to paper (105) & paperboard mills (106). Quadrant 3 at the bottom right is home to sectors which are structurally rather important, while contributing less to total GDP than sectors in quadrant 4. Given that "money" in economic analysis is usually more important than "structure"; the importance of sectors in quadrant 3 may typically be overlooked. Located in this quadrant are a large number of very diverse chemical products, with higher levels of vulnerability (price increases of up to 10%). Most of them use inputs from the petrochemical industry (120), which itself is at the border of Quadrants 3 and 4. Other sectors in the chemical-products cluster include: "Other Organic (126) & Inorganic Chemical Products (125)", Alkalies and Chlorine (123), Adhesives (137), Synthetic Dye (122) and Synthetic rubber (128). The latter and also the most vulnerable sector regarding Peak-Oil (26,6% price increase), the Carbon Black industry (124), located between Quadrant one and two, provides the main ingredients to Tire manufacturing (150), which is also located in the chemical products cluster. Synthetic rubber was a key element during World War II (WWII), as it was used on almost every war machine. Cut off from natural rubber supplies from Asia, the US launched a secret and very successful project to improve its production. Factories of the Enemies Germany and Italy on the other hand were strategically bombarded (Murphy 2008). The importance of this sector for the US economy today would probably be overlooked if one were to look at its little total contribution to GDP.

Closely related to the chemical products cluster and the highly vulnerable petrochemical sector is that of plastics, which is mainly located in Quadrant 3 and partially in Quadrant 4. This is yet another area of the US economy whose importance may be overlooked due to its little "monetary" importance. Sectors of this cluster include Plastics Material and Resin (127); Plastic Packaging (142); Plastic Pipes (144); Laminated plastics, plates, sheets and shapes (excl. packaging) (145); Polystyrene (146) and Urethane (147). To the right of plastics, at about the same latitude we find the Transport Services cluster e.g.: Pipelines (327), Trucks (325) and Airplanes (322). All of the latter are extremely vulnerable to Peak-Oil according to our definition. Finally to the left of the plastics cluster, almost in the centre of the graph, we can detect two clusters covering the same area: one being construction materials and the other textiles or fibres. Therein we find on the one hand, for example, the highly vulnerable manufacturing of Cement (160), Lime & Gypsum (164), Reconstituted Wood (98), Bricks (154), Mineral Wool (168) and Flat Glass (156) and Sand, Gravel, Clay, and Ceramic and Refractory minerals Mining and quarrying (26). On the other hand we have Synthetic Fibres (129) and Fabric, Textile, Fibre, Yarn, Thread and Fabric Coating Mills (75,78,80,81), with notable price increases

Finally, Quadrant 4 at the top right of our graph could be seen as containing the most important sectors according to our dualities – money and structure. Hence we could deduct that highly vulnerable sectors (i.e. large circles) within this quadrant are in urgent need of Peak-Oil policy action. The present economic system relies strongly on them and their outputs may become significantly more expensive due to oil price increases. One sector cluster which is mainly situated in this quadrant is that of metals and metals processing, containing for example Alumina (172), Steel (171), Iron Mills (170) and Custom roll forming (182).

There are two possible routes for such policy action: One, by moving these sectors down to quadrant one. This implies to incentivize a restructuring of the economy in order for these sectors to become less important or the economy less dependent on them e.g. ameliorating the strong dependence on artificial fertilizers (130) by promoting organic farming techniques. In other words you transform the economy in order to reduce the overall need for certain products, by initiating changes in technology and structure. Organic farming is such a technological change; a structural one could be reducing the overall distance travelled by people and goods: fostering local, decentralised economies (e.g. urban gardening, etc.) as in the case of Cuba's adaptation process during its "special period"(Friedrichs 2010). Alternatively, one could try to find substitutes from other sectors, to replace the output of vulnerable ones. Sometimes substitution may be difficult, especially if close substitutes are also located in the same (or almost the same) quadrant and show similar or worse vulnerability. We have mentioned earlier, that many other resources may also face supply limits and peaks in the future. One example for substitution difficulties may be the replacement of plastic packaging materials (142), where applicable, with packaging made from paper (108, 109) or paperboard (106,107), both of which are situated in the vicinities of sector 142 (107 at the border with quadrant 3). Another substitute for plastic packaging – glass containers (158) – does not have the same importance as paper and paperboard at the moment, but also shows high vulnerability. This means that moving from plastic to glass containers and packaging would shift that sector also towards the top right of the graph. Alumina refining (172) and alloy processing (174), the source for another possible substitute for plastic packaging is also a quite vulnerable sector of quadrant 4.

A substitution for quadrant 4 sectors based on products from existing industries is likely to encounter two problems: (1) the increased demand will inevitably shift the substituting sector towards the top right of the graph, running into the same difficulties as the sector that is being replaced; (2) if the substituting industry is mature i.e. most scale effects and cost saving possibilities have already been realized, the increasing demand will result in price increases in that sector. As indicated above we interpret such expected price increases (even if through a knock-on effect) as an increase of that sectors' Peak-Oil vulnerability. In the language of our graph this means, that sectors which are to substitute sectors located in quadrant 4 will expand and move towards the top right.

2.7 Conclusion & Outlook

The three dimensional vulnerability analysis we have presented above could be seen as a first but highly potential step towards developing tools for enhancing our knowledge about our economic system with respect to its dependency on oil. This is also the first step for developing adaptive resource management strategies, as suggested by the vulnerability and resilience literature. Our innovative tool presented here offers enormous potential for amplification, combination with other approaches, mapping developments over time, etc.

The visual preparation of the data as shown in Figure 36 moreover allows for many more interpretations and hypothesis. Taking another look at the bigger picture of the graph for example, we see that there are basically four large clusters. The one on the far right (covering both Quadrant 3 and 4), we may call the oil-age sectors. The importance of many of them may not have been significant before WWII for example. Then we have a centre-cluster which covers mainly very basic manufactured materials or processed products. At the top left we have as before primary extraction and at the bottom left to centre some more very basic agricultural or service sectors. This means that in the future our tool may be able to provide some indication of what a post-carbon society could look like.

2.8 References

Please note references of this article have been integrated in the bibliography of Part 2.

2.9 Appendix I: Full List of all sectors with numbers and results for all three models

Sector No.	Categ.	Sector name	FWLA	SNA	PM
1	1	Oilseed farming	3,07	25	3,0%
2	1	Grain farming	3,00	41	3,4%
3	1	Vegetable and melon farming	1,25	35	3,4%
4	1	Fruit farming	1,27	29	4,2%
5	1	Tree nut farming	1,31	16	4,1%
6	1	Greenhouse, nursery, and floriculture production	1,27	44	7,9%
7	1	Tobacco farming	3,10	18	4,6%
9	1	Sugarcane and sugar beet farming	2,85	16	4,4%
10	1	All other crop farming	2,66	48	5,3%
11	1	Cattle ranching and farming	3,04	14	4,3%
12	1	Dairy cattle and milk production	2,59	19	3,7%
13	1	Animal production, except cattle and poultry and eggs	2,20	38	4,3%
14	1	Poultry and egg production	2,14	38	3,5%
15	1	Forest nurseries, forest products, and timber tracts	3,70	44	3,4%
16	1	Logging	3,43	18	2,8%
17	1	Fishing	1,31	35	15,1%
18	1	Hunting and trapping	1,00	0	5,4%
19	1	Support activities for agriculture and forestry	3,32	21	3,2%
21	1	Coal mining	2,72	90	3,0%
22	1	Iron ore mining	3,37	9	7,1%
23	1	Gold, silver, and other metal ore mining	1,80	49	5,2%
24	1	Copper, nickel, lead, and zinc mining	2,40	53	5,1%
25	1	Stone mining and quarrying	2,51	29	4,1%
26	1	Sand, gravel, clay, and ceramic and refractory minerals mining and quarrying	2,12	38	4,8%
27	1	Other nonmetallic mineral mining and quarrying	1,50	55	5,7%
30	1	Support activities for other mining	1,44	9	4,6%
31	2	Electric power generation, transmission, and distribution	2,03	100	10,6%
33	2	Water, sewage and other systems	1,55	99	5,0%
34	2	Nonresidential commercial and health care structures	1,00	17	2,7%
35	2	Nonresidential manufacturing structures	1,00	13	4,2%
36	2	Other nonresidential structures	1,00	0	2,5%
37	2	Residential permanent site single- and multi-family structures	1,00	11	1,8%
38	2	Other residential structures	1,05	42	2,1%
39	2	Nonresidential maintenance and repair	2,68	99	2,8%

40	2	Residential maintenance and repair	2,12	11	1,6%
41	2	Dog and cat food manufacturing	1,03	17	2,4%
42	2	Other animal food manufacturing	2,94	27	2,5%
43	2	Flour milling and malt manufacturing	1,85	34	2,1%
44	2	Wet corn milling	2,18	41	4,0%
45	2	Soybean and other oilseed processing	2,49	48	3,0%
46	2	Fats and oils refining and blending	1,99	43	2,8%
47	2	Breakfast cereal manufacturing	1,05	21	2,1%
48	2	Sugar cane mills and refining	2,06	32	3,9%
49	2	Beet sugar manufacturing	2,02	30	4,6%
50	2	Chocolate and confectionery manufacturing from cacao beans	1,64	17	2,0%
51	2	Confectionery manufacturing from purchased chocolate	1,04	23	1,9%
52	2	Nonchocolate confectionery manufacturing	1,15	27	2,1%
53	2	Frozen food manufacturing	1,22	32	2,0%
54	2	Fruit and vegetable canning, pickling, and drying	1,38	32	2,0%
55	2	Fluid milk and butter manufacturing	1,46	37	2,7%
56	2	Cheese manufacturing	1,81	32	2,7%
57	2	Dry, condensed, and evaporated dairy product manufacturing	1,58	38	2,6%
58	2	Ice cream and frozen dessert manufacturing	1,81	26	2,0%
59	2	Animal (except poultry) slaughtering, rendering, and processing	1,57	50	2,9%
60	2	Poultry processing	1,44	33	2,3%
61	2	Seafood product preparation and packaging	1,67	28	2,1%
62	2	Bread and bakery product manufacturing	1,17	27	1,6%
63	2	Cookie, cracker, and pasta manufacturing	1,17	29	1,7%
64	2	Tortilla manufacturing	1,05	22	2,1%
65	2	Snack food manufacturing	1,17	28	2,3%
66	2	Coffee and tea manufacturing	1,37	28	1,6%
67	2	Flavoring syrup and concentrate manufacturing	2,31	31	1,9%
68	2	Seasoning and dressing manufacturing	1,49	35	2,1%
69	2	All other food manufacturing	1,35	34	1,9%
70	2	Soft drink and ice manufacturing	1,18	26	1,8%
71	2	Breweries	1,09	25	2,3%
72	2	Wineries	1,26	20	1,2%
73	2	Distilleries	1,53	26	1,7%
74	2	Tobacco product manufacturing	1,06	15	1,9%
75	2	Fiber, yarn, and thread mills	2,37	47	3,4%
76	2	Broadwoven fabric mills	1,72	57	2,8%
77	2	Narrow fabric mills and schiffli machine embroidery	1,69	41	2,3%
78	2	Nonwoven fabric mills	2,39	58	3,3%
79	2	Knit fabric mills	2,27	24	2,7%
80	2	Textile and fabric finishing mills	2,48	55	2,6%
81	2	Fabric coating mills	1,90	56	3,4%
82	2	Carpet and rug mills	1,28	29	3,3%
83	2	Curtain and linen mills	1,20	28	2,0%
84	2	Textile bag and canvas mills	1,90	48	1,7%
85	2	All other textile product mills	1,75	78	2,4%
86	2	Apparel knitting mills	1,28	10	2,0%

87	2	Cut and sew apparel contractors	2,51	29	1,6%
88	2	Men's and boys' cut and sew apparel manufacturing	1,16	32	1,6%
89	2	Women's and girls' cut and sew apparel manufacturing	1,03	23	1,6%
90	2	Other cut and sew apparel manufacturing	1,34	25	1,3%
91	2	Apparel accessories and other apparel manufacturing	1,23	38	2,7%
92	2	Leather and hide tanning and finishing	2,02	31	2,6%
93	2	Footwear manufacturing	1,01	14	1,7%
94	2	Other leather and allied product manufacturing	1,32	47	1,9%
95	2	Sawmills and wood preservation	2,46	78	2,2%
96	2	Veneer and plywood manufacturing	2,25	59	2,5%
97	2	Engineered wood member and truss manufacturing	2,18	53	1,5%
98	2	Reconstituted wood product manufacturing	2,20	52	5,7%
99	2	Wood windows and doors and millwork	2,25	79	1,6%
100	2	Wood container and pallet manufacturing	2,33	74	2,5%
101	2	Manufactured home (mobile home) manufacturing	1,03	3	1,6%
102	2	Prefabricated wood building manufacturing	2,12	33	1,4%
103	2	All other miscellaneous wood product manufacturing	2,08	87	1,8%
104	2	Pulp mills	1,75	13	4,9%
105	2	Paper mills	2,20	92	3,7%
106	2	Paperboard Mills	3,04	94	5,1%
107	2	Paperboard container manufacturing	2,49	98	2,3%
108	2	Coated and laminated paper, packaging paper and plastics film manufacturing	2,15	96	2,7%
109	2	All other paper bag and coated and treated paper manufacturing	2,25	85	2,5%
110	2	Stationery product manufacturing	2,02	56	2,0%
111	2	Sanitary paper product manufacturing	1,38	39	3,4%
112	2	All other converted paper product manufacturing	1,79	61	2,3%
113	2	Printing	2,53	82	1,7%
114	2	Support activities for printing	2,99	28	1,5%
120	2	Petrochemical manufacturing	2,66	74	22,2%
122	2	Synthetic dye and pigment manufacturing	2,21	74	6,6%
123	2	Alkalies and chlorine manufacturing	1,87	73	9,8%
124	2	Carbon black manufacturing	2,52	37	26,6%
125	2	All other basic inorganic chemical manufacturing	1,52	82	6,6%
126	2	Other basic organic chemical manufacturing	2,11	95	10,2%
127	2	Plastics material and resin manufacturing	2,60	79	9,3%
128	2	Synthetic rubber manufacturing	1,67	60	8,2%
129	2	Artificial and synthetic fibers and filaments manufacturing	2,32	54	5,1%
130	2	Fertilizer manufacturing	2,62	71	11,7%
131	2	Pesticide and other agricultural chemical manufacturing	2,36	31	3,6%
132	2	Medicinal and botanical manufacturing	2,39	12	2,1%
133	2	Pharmaceutical preparation manufacturing	1,27	32	1,0%
134	2	In-vitro diagnostic substance manufacturing	1,85	17	1,0%
135	2	Biological product (except diagnostic) manufacturing	2,13	31	0,9%
136	2	Paint and coating manufacturing	2,24	88	3,3%
137	2	Adhesive manufacturing	2,09	82	8,1%

138	2	Soap and cleaning compound manufacturing	1,58	88	3,6%
139	2	Toilet preparation manufacturing	1,09	25	2,5%
140	2	Printing ink manufacturing	2,63	45	9,0%
141	2	All other chemical product and preparation manufacturing	2,06	99	4,1%
142	2	Plastics packaging materials and unlaminated film and sheet manufacturing	2,28	94	4,4%
143	2	Unlaminated plastics profile shape manufacturing	2,51	88	3,7%
144	2	Plastics pipe and pipe fitting manufacturing	2,02	71	4,9%
145	2	Laminated plastics plate, sheet (except packaging), and shape manufacturing	2,55	77	3,0%
146	2	Polystyrene foam product manufacturing	2,31	79	4,7%
147	2	Urethane and other foam product (except polystyrene) manufacturing	2,24	77	4,2%
148	2	Plastics bottle manufacturing	2,27	47	4,7%
149	2	Other plastics product manufacturing	2,10	98	2,7%
150	2	Tire manufacturing	1,69	84	3,3%
151	2	Rubber and plastics hoses and belting manufacturing	1,58	71	2,9%
152	2	Other rubber product manufacturing	2,03	84	2,7%
153	2	Pottery, ceramics, and plumbing fixture manufacturing	1,46	61	2,7%
154	2	Brick, tile, and other structural clay product manufacturing	1,94	49	6,4%
155	2	Clay and nonclay refractory manufacturing	2,10	35	3,2%
156	2	Flat glass manufacturing	1,93	39	6,8%
157	2	Other pressed and blown glass and glassware manufacturing	1,85	79	3,0%
158	2	Glass container manufacturing	2,11	46	5,3%
159	2	Glass product manufacturing made of purchased glass	1,86	71	2,3%
160	2	Cement manufacturing	2,74	54	7,5%
161	2	Ready-mix concrete manufacturing	2,15	44	3,4%
162	2	Concrete pipe, brick, and block manufacturing	2,17	50	2,5%
163	2	Other concrete product manufacturing	2,31	73	1,9%
164	2	Lime and gypsum product manufacturing	2,31	67	7,3%
165	2	Abrasive product manufacturing	2,11	85	2,3%
166	2	Cut stone and stone product manufacturing	1,73	19	2,1%
167	2	Ground or treated mineral and earth manufacturing	2,84	42	5,1%
168	2	Mineral wool manufacturing	1,97	38	4,6%
169	2	Miscellaneous nonmetallic mineral products	1,65	41	3,9%
170	2	Iron and steel mills and ferroalloy manufacturing	2,56	90	3,3%
171	2	Steel product manufacturing from purchased steel	2,74	76	3,0%
172	2	Alumina refining and primary aluminum production	3,30	68	4,3%
173	2	Secondary smelting and alloying of aluminum	2,64	2	4,0%
174	2	Aluminum product manufacturing from purchased aluminum	2,48	70	2,6%
175	2	Primary smelting and refining of copper	2,07	48	2,8%
176	2	Primary smelting and refining of nonferrous metal (except copper and aluminum)	1,75	52	3,0%
177	2	Copper rolling, drawing, extruding and alloying	2,45	65	1,8%
178	2	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	1,45	71	1,8%

179	2	Ferrous metal foundries	2,45	65	2,4%
180	2	Nonferrous metal foundries	2,69	74	2,4%
181	2	All other forging, stamping, and sintering	2,59	74	2,9%
182	2	Custom roll forming	2,86	65	2,1%
183	2	Crown and closure manufacturing and metal stamping	2,50	86	1,8%
184	2	Cutlery, utensil, pot, and pan manufacturing	1,22	71	2,4%
185	2	Handtool manufacturing	1,65	95	1,7%
186	2	Plate work and fabricated structural product manufacturing	2,39	85	1,5%
187	2	Ornamental and architectural metal products manufacturing	2,32	82	1,4%
188	2	Power boiler and heat exchanger manufacturing	1,45	51	1,8%
189	2	Metal tank (heavy gauge) manufacturing	1,60	51	1,7%
190	2	Metal can, box, and other metal container (light gauge) manufacturing	2,39	85	2,2%
191	2	Ammunition manufacturing	1,53	19	2,2%
192	2	Arms, ordnance, and accessories manufacturing	1,16	21	1,4%
193	2	Hardware manufacturing	1,97	82	1,6%
194	2	Spring and wire product manufacturing	1,77	78	2,0%
195	2	Machine shops	2,76	98	1,5%
196	2	Turned product and screw, nut, and bolt manufacturing	2,29	91	1,5%
197	2	Coating, engraving, heat treating and allied activities	2,75	86	3,8%
198	2	Valve and fittings other than plumbing	2,31	88	1,4%
199	2	Plumbing fixture fitting and trim manufacturing	1,83	51	1,7%
200	2	Ball and roller bearing manufacturing	2,22	71	1,9%
201	2	Fabricated pipe and pipe fitting manufacturing	2,28	53	1,7%
202	2	Other fabricated metal manufacturing	1,94	99	2,2%
203	2	Farm machinery and equipment manufacturing	1,17	30	1,3%
204	2	Lawn and garden equipment manufacturing	1,24	25	1,1%
205	2	Construction machinery manufacturing	1,10	26	2,1%
207	2	Other industrial machinery manufacturing	1,25	64	1,2%
208	2	Plastics and rubber industry machinery manufacturing	1,12	31	1,1%
209	2	Semiconductor machinery manufacturing	1,23	17	1,2%
210	2	Vending, commercial, industrial, and office machinery manufacturing	1,06	44	1,8%
211	2	Optical instrument and lens manufacturing	1,01	8	1,2%
212	2	Photographic and photocopying equipment manufacturing	1,02	24	2,0%
213	2	Other commercial and service industry machinery manufacturing	1,25	78	2,4%
214	2	Air purification and ventilation equipment manufacturing	1,60	65	1,4%
215	2	Heating equipment (except warm air furnaces) manufacturing	1,60	50	1,6%
216	2	Air conditioning, refrigeration, and warm air heating equipment manufacturing	1,81	94	1,1%
217	2	Industrial mold manufacturing	1,30	33	1,7%
218	2	Metal cutting and forming machine tool manufacturing	1,12	41	1,1%
219	2	Special tool, die, jig, and fixture manufacturing	1,41	46	1,3%

220	2	Cutting tool and machine tool accessory manufacturing	2,33	91	1,4%
221	2	Rolling mill and other metalworking machinery manufacturing	1,15	23	1,1%
222	2	Turbine and turbine generator set units manufacturing	1,40	14	1,3%
223	2	Speed changer, industrial high-speed drive, and gear manufacturing	1,92	50	1,4%
224	2	Mechanical power transmission equipment manufacturing	1,69	38	1,5%
225	2	Other engine equipment manufacturing	1,61	57	1,5%
226	2	Pump and pumping equipment manufacturing	1,21	46	1,2%
227	2	Air and gas compressor manufacturing	1,08	46	1,2%
228	2	Material handling equipment manufacturing	1,35	92	1,2%
229	2	Power-driven handtool manufacturing	1,08	25	1,5%
230	2	Other general purpose machinery manufacturing	1,18	91	1,2%
231	2	Packaging machinery manufacturing	1,22	12	1,0%
232	2	Industrial process furnace and oven manufacturing	1,13	15	1,4%
233	2	Fluid power process machinery	1,88	54	1,4%
234	2	Electronic computer manufacturing	1,03	30	0,5%
235	2	Computer storage device manufacturing	1,34	49	0,7%
236	2	Computer terminals and other computer peripheral equipment manufacturing	1,19	92	0,8%
237	2	Telephone apparatus manufacturing	1,22	68	0,7%
238	2	Broadcast and wireless communications equipment	1,28	79	0,6%
239	2	Other communications equipment manufacturing	1,75	81	0,8%
240	2	Audio and video equipment manufacturing	1,07	40	1,0%
241	2	Electron tube manufacturing	1,15	46	1,3%
242	2	Bare printed circuit board manufacturing	2,47	78	1,3%
243	2	Semiconductor and related device manufacturing	1,97	86	1,0%
244	2	Electronic capacitor, resistor, coil, transformer, and other inductor manufacturing	1,24	64	1,0%
245	2	Electronic connector manufacturing	1,67	58	1,2%
246	2	Printed circuit assembly (electronic assembly) manufacturing	1,89	85	0,7%
247	2	Other electronic component manufacturing	1,92	92	0,9%
248	2	Electromedical and electrotherapeutic apparatus manufacturing	1,15	23	0,9%
249	2	Search, detection, and navigation instruments manufacturing	1,32	32	0,7%
250	2	Automatic environmental control manufacturing	2,07	41	1,1%
251	2	Industrial process variable instruments manufacturing	1,30	75	1,0%
252	2	Totalizing fluid meters and counting devices manufacturing	1,67	46	1,0%
253	2	Electricity and signal testing instruments manufacturing	1,13	24	0,9%
254	2	Analytical laboratory instrument manufacturing	1,08	32	0,8%
255	2	Irradiation apparatus manufacturing	1,05	12	0,9%
256	2	Watch, clock, and other measuring and controlling device manufacturing	1,11	47	0,8%

257	2	Software, audio, and video media reproducing	2,18	51	1,8%
258	2	Magnetic and optical recording media manufacturing	1,66	57	1,5%
259	2	Electric lamp bulb and part manufacturing	1,38	79	1,4%
260	2	Lighting fixture manufacturing	1,81	63	1,3%
261	2	Small electrical appliance manufacturing	1,18	36	1,7%
262	2	Household cooking appliance manufacturing	1,04	13	1,6%
263	2	Household refrigerator and home freezer manufacturing	1,03	13	1,7%
264	2	Household laundry equipment manufacturing	1,04	9	1,4%
265	2	Other major household appliance manufacturing	1,32	15	1,7%
266	2	Power, distribution, and specialty transformer manufacturing	1,35	74	1,9%
267	2	Motor and generator manufacturing	1,45	76	1,3%
268	2	Switchgear and switchboard apparatus manufacturing	1,64	65	1,0%
269	2	Relay and industrial control manufacturing	2,03	88	0,7%
270	2	Storage battery manufacturing	1,49	50	1,9%
271	2	Primary battery manufacturing	1,07	50	1,7%
272	2	Communication and energy wire and cable manufacturing	2,17	75	1,8%
273	2	Wiring device manufacturing	1,88	75	1,7%
274	2	Carbon and graphite product manufacturing	2,06	38	5,5%
275	2	All other miscellaneous electrical equipment and component manufacturing	1,18	68	0,9%
276	2	Automobile manufacturing	1,00	2	0,7%
277	2	Light truck and utility vehicle manufacturing	1,00	6	0,7%
278	2	Heavy duty truck manufacturing	1,04	25	1,2%
279	2	Motor vehicle body manufacturing	1,55	27	1,1%
280	2	Truck trailer manufacturing	1,01	9	1,1%
281	2	Motor home manufacturing	1,01	2	1,1%
282	2	Travel trailer and camper manufacturing	1,11	25	1,4%
283	2	Motor vehicle parts manufacturing	1,90	99	0,8%
284	2	Aircraft manufacturing	1,25	12	0,8%
285	2	Aircraft engine and engine parts manufacturing	1,76	23	1,1%
286	2	Other aircraft parts and auxiliary equipment manufacturing	1,61	25	1,4%
287	2	Guided missile and space vehicle manufacturing	1,54	10	0,8%
288	2	Propulsion units and parts for space vehicles and guided missiles	1,87	14	1,1%
289	2	Railroad rolling stock manufacturing	1,14	24	0,9%
290	2	Ship building and repairing	1,22	10	1,2%
291	2	Boat building	1,02	11	1,0%
292	2	Motorcycle, bicycle, and parts manufacturing	1,05	12	1,1%
293	2	Military armored vehicle, tank, and tank component manufacturing	1,02	3	1,2%
294	2	All other transportation equipment manufacturing	1,13	36	1,1%
295	2	Wood kitchen cabinet and countertop manufacturing	2,04	53	1,5%
296	2	Upholstered household furniture manufacturing	1,01	16	1,5%
297	2	Nonupholstered wood household furniture manufacturing	1,01	4	1,6%

298	2	Metal and other household furniture (except wood) manufacturing1	1,15	31	2,1%
299	2	Institutional furniture manufacturing	1,11	18	1,5%
300	2	Wood television, radio, and sewing machine cabinet manufacturing1	1,94	18	1,8%
301	2	Office furniture and custom architectural woodwork and millwork manufacturing1	1,25	10	1,4%
302	2	Showcase, partition, shelving, and locker manufacturing	1,26	50	1,8%
303	2	Mattress manufacturing	1,03	12	1,7%
304	2	Blind and shade manufacturing	1,03	13	1,5%
305	2	Laboratory apparatus and furniture manufacturing	1,04	34	1,3%
306	2	Surgical and medical instrument manufacturing	1,39	29	1,1%
307	2	Surgical appliance and supplies manufacturing	1,51	72	1,2%
308	2	Dental equipment and supplies manufacturing	1,52	19	1,4%
309	2	Ophthalmic goods manufacturing	1,06	51	1,4%
310	2	Dental laboratories	1,93	8	0,9%
311	2	Jewelry and silverware manufacturing	1,12	37	1,3%
312	2	Sporting and athletic goods manufacturing	1,10	35	1,7%
313	2	Doll, toy, and game manufacturing	1,03	21	2,4%
314	2	Office supplies (except paper) manufacturing	1,45	90	2,3%
315	2	Sign manufacturing	1,16	14	1,7%
316	2	Gasket, packing, and sealing device manufacturing	1,86	72	2,1%
317	2	Musical instrument manufacturing	1,11	20	1,1%
318	2	All other miscellaneous manufacturing	1,41	69	1,7%
319	2	Broom, brush, and mop manufacturing	1,72	68	2,8%
320	3	Wholesale trade	1,77	100	0,3%
321	3	Retail trade	1,13	99	0,2%
322	3	Air transportation	1,60	100	10,7%
323	3	Rail transportation	2,45	100	5,2%
324	3	Water transportation	1,45	98	2,0%
325	3	Truck transportation	2,02	100	6,1%
326	3	Transit and ground passenger transportation	1,64	100	10,4%
327	3	Pipeline transportation	2,70	99	18,5%
328	3	Scenic and sightseeing transportation and support activities for transportation	2,68	100	3,7%
329	3	Couriers and messengers	2,82	40	10,2%
330	3	Warehousing and storage	2,56	100	2,1%
331	3	Newspaper publishers	1,08	53	1,4%
332	3	Periodical publishers	1,52	86	1,4%
333	3	Book publishers	1,30	36	1,2%
334	3	Directory, mailing list, and other publishers	1,65	35	1,2%
335	3	Software publishers	1,24	46	0,5%
336	3	Motion picture and video industries	2,26	33	0,6%
337	3	Sound recording industries	1,53	27	1,1%
338	3	Radio and television broadcasting	2,72	4	1,1%
339	3	Cable and other subscription programming	3,15	25	1,1%
340	3	Internet publishing and broadcasting	2,90	27	1,4%
341	3	Telecommunications	1,93	100	0,4%

342	3	Internet service providers and web search portals	1,57	100	0,9%
343	3	Data processing, hosting, and related services	2,70	95	0,9%
344	3	Other information services	1,79	59	1,8%
345	3	Monetary authorities and depository credit intermediation	2,03	99	0,2%
346	3	Nondepository credit intermediation and related activities	2,25	99	0,3%
347	3	Securities, commodity contracts, investments, and related activities	2,06	99	0,2%
348	3	Insurance carriers	1,55	96	0,1%
349	3	Insurance agencies, brokerages, and related activities	2,78	20	0,5%
350	3	Funds, trusts, and other financial vehicles	1,17	11	0,4%
351	3	Real estate	1,99	100	0,2%
352	3	Owner-occupied dwellings	1,00	0	0,1%
353	3	Automotive equipment rental and leasing	1,92	99	0,5%
354	3	General and consumer goods rental except video tapes and discs	1,58	93	0,9%
355	3	Video tape and disc rental	1,00	0	0,7%
356	3	Commercial and industrial machinery and equipment rental and leasing	2,67	99	0,8%
357	3	Lessors of nonfinancial intangible assets	2,97	97	0,6%
358	3	Legal services	2,02	100	0,2%
359	3	Accounting, tax preparation, bookkeeping, and payroll services	2,54	100	0,5%
360	3	Architectural, engineering, and related services	2,26	97	0,7%
361	3	Specialized design services	2,64	97	1,0%
362	3	Custom computer programming services	1,09	49	0,7%
363	3	Computer systems design services	2,23	100	0,8%
364	3	Other computer related services, including facilities management	2,73	100	0,6%
365	3	Management, scientific, and technical consulting services	2,73	97	0,6%
366	3	Environmental and other technical consulting services	2,55	96	1,0%
367	3	Scientific research and development services	2,26	96	1,1%
368	3	Advertising and related services	2,80	97	0,6%
369	3	All other miscellaneous professional, scientific, and technical services	2,84	97	0,7%
370	3	Photographic services	1,58	21	1,2%
371	3	Veterinary services	1,20	20	1,0%
372	3	Management of companies and enterprises	2,74	100	0,2%
373	3	Office administrative services	2,65	96	0,8%
374	3	Facilities support services	2,40	94	1,2%
375	3	Business support services	2,59	99	1,1%
376	3	Investigation and security services	2,25	96	1,0%
377	3	Services to buildings and dwellings	2,48	100	10,7%
378	3	Other support services	2,29	97	1,4%
379	3	Employment services	2,73	97	0,3%
380	3	Travel arrangement and reservation services	2,12	100	1,5%
381	3	Waste management and remediation services	2,29	97	2,1%

382	3	Elementary and secondary schools	1,00	0	1,3%
383	3	Junior colleges, colleges, universities, and professional schools	1,11	42	1,5%
384	3	Other educational services	1,15	76	1,0%
385	3	Offices of physicians, dentists, and other health practitioners	1,00	16	0,2%
386	3	Medical and diagnostic labs and outpatient and other ambulatory care services	1,19	19	0,7%
387	3	Home health care services	1,00	2	1,4%
388	3	Hospitals	1,00	16	0,4%
389	3	Nursing and residential care facilities	1,00	16	0,8%
390	3	Individual and family services	1,02	14	1,0%
391	3	Community food, housing, and other relief services, including rehabilitation services	1,00	14	1,0%
392	3	Child day care services	1,03	15	1,1%
393	3	Performing arts companies	1,52	91	1,0%
394	3	Spectator sports	2,22	97	1,1%
395	3	Promoters of performing arts and sports and agents for public figures	2,11	96	1,3%
396	3	Independent artists, writers, and performers	2,89	96	0,7%
397	3	Museums, historical sites, zoos, and parks	1,00	0	2,0%
398	3	Amusement parks, arcades, and gambling industries	1,00	9	2,7%
399	3	Other amusement and recreation industries	1,34	97	1,8%
400	3	Fitness and recreational sports centers	1,34	94	1,7%
401	3	Bowling centers	1,02	4	2,4%
402	3	Hotels and motels, including casino hotels	1,88	99	1,5%
403	3	Other accommodations	1,02	21	2,8%
404	3	Food services and drinking places	1,40	99	0,7%
405	3	Automotive repair and maintenance, except car washes	1,48	99	0,7%
406	3	Car washes	1,32	93	2,5%
407	3	Electronic and precision equipment repair and maintenance	2,29	99	1,1%
408	3	Commercial and industrial machinery and equipment repair and maintenance	2,79	98	1,2%
409	3	Personal and household goods repair and maintenance	1,99	96	1,2%
410	3	Personal care services	1,02	14	0,8%
411	3	Death care services	1,00	0	1,6%
412	3	Dry-cleaning and laundry services	1,60	83	2,0%
413	3	Other personal services	1,17	33	1,0%
414	3	Religious organizations	1,00	0	0,6%
415	3	Grantmaking, giving, and social advocacy organizations	1,01	4	0,9%
416	3	Civic, social, professional, and similar organizations	1,76	98	1,0%
417	3	Private households	1,00	0	0,0%
418	3	Postal service	2,45	85	2,2%
419	3	Federal electric utilities	1,05	30	4,8%
420	3	Other Federal Government enterprises	2,28	13	2,4%
421	3	State and local government passenger transit	1,00	0	0,0%
422	3	State and local government electric utilities	1,11	65	0,0%

423	3	Other state and local government enterprises	1,37	94	0,0%
424	3	General Federal defense government services	1,00	0	0,7%
425	3	General Federal nondefense government services	1,00	4	1,2%
426	3	General state and local government services	1,00	0	1,4%
427	3	Scrap	1,82	40	2,8%
428	3	Used and secondhand goods	1,06	24	0,0%

3 Concluding remarks – Vulnerability and Peak Oil

A transition towards a low-carbon economy will require enormous efforts from our society (Hirsch, Bezdek et al. 2005) – some even say it is impossible (Sorman and Giampietro in press). However as even Joseph Tainter once said in a presentation "we cannot just give up". Because of the large uncertainties involved this process needs to be participative (Walker, Carpenter et al. 2002): from all levels of public administration until the most divers social groups (entrepreneurs, unions, neighbour and consumer associations, environmentalists, etc.).

The importance and magnitude of the challenge we face requires the initiation of debates and social dialogues and if possible national and international agreements. In many cases these transformations may be traumatic and trigger socioeconomic conflict (Leder and Shapiro 2008; Friedrichs 2010), thus, to minimize these tensions, public institutions should create a widespread social awareness of the important issue of Peak Oil. On an international level nation states are likely to take strategic decisions, once oil supply starts to permanently fall short of supply due to peak oil (Elsayed and Elrefaai 2008; Friedrichs 2010). The economic, social, geopolitical and environmental repercussions of such decisions will determine, without any doubt, the planet's future.

Very concrete policy recommendations from the analysis presented in this chapter would most likely be premature still. More research is certainly necessary. However time is precious and some general recommendations may be possible. At the sector level, a transition towards a new more efficient transport system is key. However, this doesn't necessarily entail the construction of new infrastructures. In the past we have invested great amounts of resources in infrastructures, which we should take advantage of and which need to be paid off (Chester and Horvath 2009).

In general, the most beneficial solution from an energy-oriented view would be to look for alternatives to maximize the use of already existing infrastructures; for example, by promoting collective transport or by adapting them to other modes of transport, as practiced in the Cuban case (Quinn 2006).The reduction of mobility needs should probably become one of the main objectives in our political agenda. In order to so, in the first place, we have to reconsider our territorial structure in order to bring different uses closer together. Secondly, we have to bring producers closer to each other, and to consumers: maybe this is the time to start talking seriously about regionalization instead of globalization (Bailey, Hopkins et al. 2010).

Advancing towards a post-carbon society will require substantial amounts of economic resources. Due to lower levels of economic activity induced by peak oil, tax revenues will decline, coupled with higher needs for unemployment benefits. Both circumstances will increase public deficit while reducing the amount of resources available for achieving the transition. This is why the efficiency of public spending and investment is a key variable for managing the transition.

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PART 3 [Paper III & Paper IV]

Attitudes towards technology Sustainability and Peak-Oil

1 PAPER III

A framework of attitudes towards technology in sustainability studies, applied to teachers of ecological economics[110]

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1.1 Abstract

Technology can be a problematic issue for sustainability studies: rebound effects to technology-based efficiency improvements can imply absolute increases of resource use; technology helps to improve food security, but also erodes biodiversity, etc. When addressing such issues ecological economics may support some technological solutions and question others. Hence attitudes towards technology, within the discipline, cover a wide spectrum and can at times be contradictory and hidden. In order to facilitate the orientation of scholars and beneficiaries of research and teaching in ecological economics, within this spectrum, we propose a holistic framework for its conceptualisation. Such a framework allows the transparent articulation of differing technology-positions, which we believe is vital for teaching and research in ecological economics. Our framework stretches from technological scepticism, over romanticism and determinism, until technological optimism and is derived from social and philosophical studies of technology. In between we define our own categories such as plain pessimism, entropy pessimism, the post-normal-science-view of technology and entropy optimism.

Thereafter we apply our framework to teaching material of international researchers that taught PhD students in ecological economics. Specifically we ask what attitudes towards technology are found in this material and how these relate to each other. Subsequently we trace those attitudes to personal backgrounds and self-perceptions of the teachers. A qualitative content analysis of lecture texts and questionnaire answers by teachers revealed

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patterns of attitudes and their relations to researchers' backgrounds. Teachers express explicit and implicit attitudes towards technology that contradict to varying degrees within single presentations and among colleagues. Optimistic and critical attitudes towards technology exist alongside ambiguous positions. Often patterns of attitudes differ among teachers. Topics of presentations can explain attitudinal expressions to some extent. But expressions can also be mere rhetoric devises. Personal backgrounds and self-perceptions of teachers, however, offer only limited explanations of attitudes.

Overall this implies a risk of lacking transparency in arguments made by ecological economics teachers and scholars. It is often unclear to what extent statements about technology relate to research findings or to personal attitudes. Technology is an important aspect of sustainability research and teachers may not be seen credible by their audience, if positions on technology are not clearly stated. Ecological economics lacks a disciplinary canon on the role of technology. Considering the diversity and uncertainty of technologies discussed we should perhaps simply acknowledge the multitude of attitudes and backgrounds of ecological economists. But this requires transparency of personal positions.

1.2 Keywords

technology, attitudes, case study, education, ecological economics

1.3 Introduction

Throughout history technological change had significant effects on human society, which commonly are seen as advancements. In the twentieth century, however, attitudes towards technology gradually shifted to more differentiated perspectives that in parts are more sceptical of technology. Technological disasters like Tsernobyl or Bhopal are seen to have contributed to more critical attitudes (compare Mitcham 1994). One could even speculate that technological advances, with few exceptions, like information technology, have become less important for society over the last decade. Moreover, at the end of the twentieth century critical post-modern positions on objectivity in science gained importance (e.g. Funtowicz and Ravetz 1994). These emphasise that the presence and attitudes of the researcher influence the outcomes of research, which requires making personal and institutional assumptions and attitudes explicit to recipients of the research, because on this basis the audience can better qualify the results.

This paper focuses on researchers' individual perceptions of the role of technology in sustainability studies - an area where critical post-modern positions are particularly pronounced (Funtowicz and Ravetz 2008). Particularly, ecological economists and related researchers have long criticized and departed from the blanket technological optimism, which dominates orthodox economic literature (Costanza 1989). But even these researchers have significantly varying opinions on the role of technology for sustainability. For example, some warn that technologies, which use resources more efficiently, also encourage increased use of resources that are then no longer available for future purposes (e.g. Binswanger 2001; Alcott 2005). Others, in turn, suggest that "environmental innovations" (e.g. von Weizsäcker, Lovins et al. 1997; Ayres 2008) or "technological transfer" (Ockwell and Rydin 2006) will support sustainability.

Up to now such prepositions on technology articulated in literatures and oral presentations of researchers have not been thoroughly explored. The paper aims to address these questions. To bring positions on technology to the open we developed a general framework that guides our empirical analysis. We content that when differing attitudes towards technology enter sustainability research it may have significant implications for its conduct, content and outcomes. The paper rest on a case study of the 2009 THEMES summer school in Brighton, which was initiated by the European Society of Ecological Economics. The school addressed questions of sustainability and explicitly discussed innovations and technology from a diversity of angles. Specifically, we explore the explicit and implicit attitudes towards technology in the teaching material of that event.

This led us to extract conceptual backgrounds for "technology" from the literature that are used to build a framework of attitudes towards technology. Subsequently this framework is applied to the empirical case. The implications of our results are critically discussed. Most importantly we argue for a need to make stances on technology more explicit, if sustainability research is to be taken seriously.

1.4 Conceptual Background

A major challenge when studying individual attitudes towards technology is finding an adequate definition of the term "technology". Commonly, dominant perspectives on technology (Mitcham 1994) and science (Kuhn 1962) change over time, which may lead to differing interpretations of the term "technology".

Carl Mitcham for example defines technology as the *"making and using of artefacts"*, which he claims to be a largely unreflected activity as most engagements with technology happen by habit no matter whether in high-technology or less-technology societies (Mitcham 1994). In his widely cited book "Diffusion of Innovations" Everett Rogers defines technology with a more consequentialist connotation: *"…A technology is a design for instrumental action that reduces the cause-effect relationships involved in achieving a desired outcome."* (Rogers 2003, p. 13). He proposes to divide a technology in a) a "hardware aspect", which consists of the tool as a material or physical object embodied in the technology and b) a "software aspect" that consists of the information base for using the tool. These two attempts to define technology share in common that they point at the social aspects of technology – how we deal with technology habitually and purposely. While these reflections helped developing our framework, we realized that broad definitions of technology were detrimental to our goal of mapping attitudes. When defined broadly enough, almost any human (or even animal) action involves the use of technology, including language or cultural practices.

It is important to note that technology is not given or static. Most discussions are about technological innovation and the diffusion of technology. Invention of technology is commonly seen as something happening before innovation and diffusion, as it concerns the development of entirely new artefacts. The social process of making them usable in practice would then be *technological innovation*. These ideas derive to large extents from Joseph Schumpeter who emphasised the role of technology and entrepreneurial innovation in capitalist economies (Schumpeter 1952). *Technological advancement* also relates to innovation, but is mostly an expression for *technological change* at broader scales with connotations of progress. Both concepts are often seen as core drivers for *economic* change. Before the twentieth century technological change was not as rapid and encompassing as today – especially at a global scale (Cameron and Neal 2003). Accordingly, historical descriptions suggest that in medieval or biblical times technology was given and hence the resources available to an economy set the upper limit to its economic achievements (Cameron and Neal 2003). *Technological change* is held to expand those limits by discovering more resources and using them more efficiently, which then enables economies to be inhabited by larger populations with higher standards of living (Cameron and Neal 2003). Such arguments essentially boil down to a notion of economic growth based on technological progress and they immediately raise questions of sustainability. But there are more differentiated views on technology.

1.5 A framework for the evaluation of attitudes towards technology

Our framework or continuum of categories draws heavily on Mitcham's (1994) "three ways of being with technology", which constitute different ideal types of (social) relationships of humans with technology: ancient scepticism, enlightenment optimism and romantic uneasiness. Mitcham's framework focuses at the "modes of the manifestation of technology" (Mitcham 1994, p. 160). Technology can thereby be distinguished according to types of objects (utilities, tools, machines), knowledge (maxims, rules, theories), activity (making, designing, maintaining, using) and volition (active will, receptive will) (Mitcham 1994, p. 268). These can be translated into categories of implicit and explicit approaches or attitudes towards technology. But this requires us to transform Mitcham's framework. Our four main "techno-attitude" categories are called: technological scepticism, romanticism, determinism and optimism. We depart from Mitcham's ordering, since we aim at a continuum of possible attitudes, for which we develop subcategories. Nevertheless establishing categories is problematic. They overlap, and their boundaries are debatable and to some extent arbitrary as also Mitcham points out (Mitcham 1994). But building categories helps to detect inconsistencies and incoherence and thus forces to reason and reflect on attitudes and approaches towards technology.

1.5.1 Technological Scepticism

Mitcham's "ancient scepticism", describes attitudes towards technology during ancient or premodern times (Mitcham 1994). Technology was seen with greatest suspicion and unease. It bore the danger of being turned away from God or the gods until it had been established that it was innocent or necessary. This conforms to the view that technologies of today tend to cause environmental and ecological problems. Consequently technology needs external guidance. But there will always be hidden dangers in technologies.

There is a wide array of scepticisms concerning technology. Some may argue it undermines social cohesion, fosters individualisation and isolation or that it eliminates jobs and/or erodes their meaning (e.g. Fromm 1956; Illich 1973). From an environmental perspective technologies enable quicker exploitation of natural resources (Daly und Cobb 1994) e.g. using chainsaws instead of axes (McNeill 2001), an argument closely related to the rebound effect. Røpke on the other hand criticises the unified attention on technology for solving environmental problems, as this is likely to imply that underlying social conditions are not accounted for. (Røpke 1996). Daly and Cobb also conclude that *"…The assumption that new technology will solve the problem, …, does not hold up."* (Daly und Cobb 1994)

More generally sceptics may argue that technology almost always involves the creation of a-natural substances and processes, which tend to damage or disrupt natural ecological cycles. It could thus be seen as a means used by man to exert power and control over other human beings and the environment.

Within the category of technological scepticism we identify three subgroups: (a) Simple Scepticism, (b) Technophobes (plain pessimists) and (c) entropy pessimists.

Simple scepticism (a) implies that technology has to proof that it does not have drawbacks that cannot (readily or fundamentally) be mitigated. Therefore, risk assessment is needed. However, this suggests that it is possible to assess technology, which gives some hope, but only over a certain time while there is still a chance of technological failure. Optimism is thus only articulated in terms of means for assessment, but potentially it may just be proven that all technologies finally fail. Daly and Cobb cite Victor Furkiss, who argued in 1974 that the current society is locked in a positive feedback loop, where *"…technological change feeds on itself, …"* and thus *"…ecological humanism must create an economy in which…, technology is controlled, …"* (Victor Furkiss 1974: 235 cited in (Daly und Cobb 1994). .

Plain pessimism or technophobia (b) (Drengson 1982) could be described as a luddite rejection of all new technology. Representatives may attribute all or most problems of human society to this factor (e.g. poverty, inequality, environmental distruction, etc.) and they may be quite pessimistic about human's destiny. The only hope for a sustainable future may be in reverting to simpler "low-tech-no-tech" lifestyles, integrating the human economy with ecological cycles and applying traditional knowledge. The Amish may be regarded as a societal group practicing this philosophy. The Luddite's fear of technology reawakened after the WWII bombings of Hiroshima and Nagasaki and later in the opposition to nuclear power. Technology gone wrong is also a reoccurring theme in the arts from Mary Shelley's 'Frankenstein' to science fiction movies like the Wachowski Brothers' Matrix Trilogy.

Some academic support for this view is provided by the Jevons or Rebound Effect (see for example Binswanger 2001). A more radical version of this hypothesis has been suggested by (Schneider 2008), who postulates that technological improvements always serve to overcome limits (time, distance, speed, weight, etc.), which eventually will result directly or indirectly in negative environmental, social and economic impacts. Instead we should not intend to overcome, but to embrace these limits (Schneider, Nordmann et al. 2002; Schneider 2008). This position is also articulated by the emerging field of de-growth economics (e.g. Ariès 2004; Latouche 2004; Baykan 2007).

The term 'entropy pessimism' (c) has been used by Robert (Ayres 2007), who himself refers back to (Pezzey and Toman 2002) and he provides Nicolas Goergescu-Roegen (1971; 1975; 1976; 1977; 1993) and Herman Daly (1987; 1992; 1992a) as representatives thereof. It is the counterpart to the 'neoclassical economic technological optimism', which we will refer to later. This debate has its roots, in early classical economic concerns of limits of agricultural output (Malthus 1807 [1798]; Ricardo 1821 [1817]; 1826 [1798]) and non-renewable resources (Jevons 1866 [1865]) and re-emerged in the late 60ies and 70ies (e.g. Georgescu-Roegen 1971; Meadows, Meadows et al. 1972; Schumacher 1973). Its authors could also be regarded as one of the first supporters of "strong sustainability" (Ayres 2007), and many of their arguments are based on thermodynamics.

For Georgescu-Roegen (1975) there had only been two "viable technologies" in human history so far: fire and the steam engine, as these were the only discoveries that would produce more energy than they consumed. All other technology could be seen as mere attempts to use and employ (or waste?) the available stock of fossil energy at a faster rate. Without our enormous fossil fuel derived energy affluence, most technology, would simply not exist, which is true even for some so called renewable energy technologies. This position is supported by many peak oil theorists (e.g. Campbell and Laherrere 1998). Moreover no technology is able to reverse the arrow of entropic degradation of energy and materials (Georgescu-Roegen 1971, p. 60), a position, which has been challenged by followers of the "energy dogma" (Ayres and Nair 1984; Ayres and Kneese 1990; Ayres 1994; 1997; 1998; 1999). On the other hand, the claim that sink capacities of the planet's ecosystems are reaching its limits or have already been surpassed, remains mostly unchallenged (Ayres 1998). It is thus argued technological advances will not be enough or because of the rebound effect (Binswanger 2001) will even worsen the problem of scale as illustrated by the Ehrlich (1971) equation (I=P*A*T).

For Tainter, (2000; Allen, Tainter et al. 2002), technological advances are also not a sign of progress, but instead the result of an increasing societal complexity due to crises and scarcity and driven by population growth. Without this pressure people would still live the way indigenous tribes do, which tend to work much less than people in modern societies. Eventually, he argues, societies tend to become too complex to maintain and they collapse.

1.5.2 Technological Romanticism and Post-Normal-Science

Carl Mitcham claims an "an uneasiness" about the "modern technological project" that derives from philosophical reflection and experiences made with technology in the twentieth century such as nuclear weapons and environmental pollution (Mitcham 1994). Opinions emerged that critics of technology have to take its benefits into account and that proponents have not only to consider its complexity and fragility in the environment but also the moral arguments of technology critics (Mitcham 1994). Within such "romantic uneasiness" technology is seen as questionable and associated with feelings of unease, but these relations are ambivalent and hence, sublime aspects would essentially determine the viability of a technology (Mitcham 1994).

Technological romanticism is situated in the ambiguous middle between technological optimism and pessimism, within which it can tend more towards pessimism or optimism. Hence, we have divided this category into (a) an ambivalence about technology, that emphasizes the possibility of drawbacks and (b) an ambivalence that emphasizes the possibility of benefits. These perspectives are close to the Post-Normal-Science (PNS) views on technology (c), which focuses on many technological aspects of science, particularly complexity, risk and uncertainty of technology deployment (Ravetz, Funtowicz, und Costanza 2008). PNS is therefore a third subcategory.

Evolutionary concepts of technology that are non-deterministic may also fall into romantic uneasiness, because all kinds of outcomes are possible, but it remains unclear what could be desirable. The ethical underpinnings of evolution are not clear-cut. Exceptions are e.g. Huxley's dualistic argument of the fittest being not necessarily the ethically best (Huxley 1970), while Herbert Spencer suggests the fittest to be the best, and John Dewey conceives ethics part of cultural evolution and thus itself evolving (Nitecki 1994). The sociobiological ideas of Edward O. Wilson also met diverse ethical perspectives (Caplan 1976; Richards 1986). Therefore evolutionary stances on technology can be extremely ambiguous.

(a) Ambivalence about technology that emphasizes the possibility of drawbacks

Martin Heidegger argues that technology invites its questioning and also has to be questioned in order to experience it (to exist) (Heidegger 2009). Heidegger sees dangers in too much technology, but also a close relation of humans with technology (Mitcham 1994, p. 55). Similarly ambiguously Lewis Mumford argues that only human demands and aspirations are the reasons for making up the mind about technological means (Mitcham 1994, pp. 42-43). These can either be "polytechnics" that are life-oriented and work for the democratic realisation of the diversity of human potentials or "monotechnics" that work in authoritarian processes towards economic expansion, resource depletion and military power (Mitcham 1994). Technology may for example "weaken social bonds of affection" and "alienate from affective strength" to exercise technology (Mitcham 1994, p. 299). Thus, an ambiguous uneasiness about technology is being articulated and although it may be beneficial there is more pronounced speculation about negative aspects. Such equivocal attitudes imply indecisive opinions on how to treat technology.

(b) Ambivalence that emphasizes the possibility of benefits

Although it may have drawbacks, possible positive aspects of the technology that are made rather specific may be at the forefront. Such uneasiness concerning technology implies that hopes associated with technology are emphasised while it remains unclear how to treat technology. For example, Mumford's "polytechnics" could be the focus, because they are life-oriented and work for the realisation of the diversity of human potentials. At personal levels technology thus "engenders freedom" (Mitcham 1994). Further, the "will to technology is an aspect of creativity" and the "artefacts expand the process of life and reveal the sublime" (Mitcham 1994). But it is unsure how one actually can arrive at the conditions of such prospects.

(c) Post-Normal-Science (PNS) view on technology

The PNS view on technology relates to romantic uneasiness, as it calls for a new definition of *quality* in the management of complex science-related issues: If decisions have to be made about 'if', or 'how' to apply or support a new technology and if the system uncertainties are very high and so are the 'decision stakes', then a process of extended peer review should be initiated (Funtowicz and Ravetz 2008). Such a process acknowledges the plurality of legitimate perspectives, which PNS upholds, because the traditional reliance on the Descartian notion of scientists as the beholders of the "truth" and "sound science" ignores two important facts (Funtowicz and Ravetz 2008): First, the uncertainty and complexity of social and biophysical systems and second the bias and disagreement that exists among most experts (Wynne 1992; Yearley 1999; Maranta, Guggenheim et al. 2003; Lessard 2007).

This approach is claimed to be needed when choosing which technology should be support the achievement of sustainability goals e.g. nuclear power or renewable energy. Often this is addressed by unqualified pro science and technology statements, which portray all technological advancements as intrinsically good and synonymous of human progress (e.g. Broers 2005; cited by Stirling 2007). Even when public participation processes are deployed, these face a risk of being degraded to therapy or plain manipulation (Arnstein 1969) or to "technologies of legitimisation" in order to 'close down' a wider political discourse (Harrison and Mort 1998; cited by Stirling 2008). Stirling (2007) therefore calls for rigorous, complete and inclusive processes of transparent stakeholder deliberation (starting from the initial 'framing').

Such 'upstream engagement' (Wilsdon and Willis 2004; cited by Stirling 2007) should not obscure the essentially normative and political character of technological choices. Generally, within attitudes of romantic uneasiness, it is not clear whether PNS positions really maintain a middle ground regarding technology for sustainability. The future may be a "technological" one, which is certainly true if technology is defined widely enough (Stirling (2007). But, depending on the definition of technology, an impression remains that returning to less advanced technologies or to no technology at all is implicitly being ruled out.

1.5.3 Technological determinism

When it is held that technology is dynamically progressing, technological change is seen as automatic or at least "quasi-automatic" because the productivity of capital is partly a function of the embodied technology (Cameron and Neal 2003). Similarly deterministic Jaques Ellul defines as *"…the totality of methods rationally arrived at and aiming at absolute efficiency (for a given stage of development) in every field of human activity"* (Elull 1954, cited by Mitcham 1994, p. 57). Technology thereby replaced capital as the dominant force in the economic progress and thus the natural environment is being replaced with a technical environment (Mitcham 1994, p. 60). For constructivists, however, technologies are “social constructions” to a similar degree as they are technological constructions (Mitcham 1994). Determinism may thus be seen open at some point, though only from the social sphere. But even then, as Francis Fukuyama argues, some groups will always develop technology, no matter whether catastrophic events destroy its infrastructure, or people decide to abandon technology. This is simply because, if some humans survive, technological knowledge will do so as well and technology will be used, because it enables groups to defend themselves against others (Fukuyama 1993).

Evolutionary approaches towards technology can be deterministic, although it is widely held that evolution is an open process. Within evolutionary approaches it is not questioned whether technologies are good or bad. Rather it is focused at the mechanisms that drive and transmit technological change (e.g. Nelson und Winter 1982) and it is those mechanisms which can be portrayed as deterministic. This is common in evolutionary economics, where determinants are variation, inheritance, inevitability and selection of properties. These can only be relaxed by degrees of human intentionality (Hodgson 2004). For example, co-evolution of society and ecology suggests that more complex socio-technical systems evolve that cope with a decreasing diversity of natural ecosystems (Norgaard 1981; Norgaard 1994). While such arguments are rather deterministic, the emergence of random feed-backs can also be seen as non-deterministic, suggesting relativity and reflexive post-normal perceptions of technology. However, this category focuses on general technological determinism where outcomes have no specific value.

1.5.4 Technological Optimism

Although the term “technological optimism” is being used in the academic literature, we could not find a prober definition for it. Here we would describe it as the positivistic belief that all phenomena, which are detrimental to the goals followed by humans, can be effectively removed or overcome by humanly devised technology. Alternatively we could define it as an attitude towards technological advances, which assumes that at one point in the future humans will be able to understand and control all relevant variables of any given process on earth and beyond, if they wish to. This position therefore is related to the Descartien view of men’s role in this world as “master and possessors of nature” (Funtowicz and Ravetz 2008). Hence it is a result or symptom of “normal science”, which sees science as a puzzle solving activity within an unquestioned and unquestionable ‘paradigm’, as Kuhn (1962) defined it (Funtowicz and

Ravetz 2008). These enthusiastic ideas about technology are based on modern Enlightenmentattitudes (Mitcham 1994). Technology therein is inherently good and its misuses are accidental. Hence, the burden of proof is with those who oppose new technologies. We have subdivided this group into the (a) technophiles, (b) technocrats and (c) entropy optimists.

The most extreme forms of 'technological optimism' are those of the technophile (a) and the technocrat (b). The technophile sees all or most technology as intrinsically good and beneficial for humans (especially high technology). This person would adopt technologies enthusiastically and expects them to improve life and solve social problems (Drengson 1982). A technocrat would go even further than this, as he/she believes in "rule by experts" or that decision-makers should be selected based on their specialized, technological knowledge, and/or rule according to technical processes. It is believed that this would greatly improve efficiency and reduce socio-economic irrationalities(Brunham 1941). In less radical forms, traces of technocratic attitudes can be found in all forms of 'technological optimism' and most prominently in the language of 'sound science' (Stirling 2007) of the common pro-technology political discourse. Therein technology is believed the main determinant of the future of the human society; where history can be reduced to a one way track "race to advance technology" (Broers 2005; cited by Stirling 2007). Another typical characteristic of this attitude is its apparent intolerance towards technological sceptics, even if moderate. those critical of technology, even if scepticism is moderate, which may be referred to as 'enemies of reason' (Taverne 2005; cited by Stirling 2007) or '...member(s) of the "flat earth society", opposed to ... modern life itself' (Malloch-Brown 2001; cited by Stirling 2007).

An optimistic attitude towards technology could be seen as an essential component of neoclassical economic theory, which we shall call entropy optimist (c). In summary, and according to our analysis technological optimism in neoclassical economic theory has the following rationale: Continuing unlimited economic-growth is an "*axiomatic necessity*" (Georgescu-Roegen 1977, p. 266) to rid society of most social evils like unintentional unemployment, poverty, overpopulation (the poor have less children) and pollution (the rich care more about their the environment as they can afford the "luxury") (compare World Bank 1992; Spence 2008; World Bank 2008). Technological progress justifies the assumption of perfect substitutability of the factors of production, which feed this unlimited economic growth (compare Solow 1956; Barnett and Morse 1963). Not only are scarce (or exhausted) materials substituted for new, more abundant ones (compare Dasgupta and Heal 1974; Stiglitz 1974; Solow 1974a; Solow 1974b; Stiglitz 1979) but also are material intensive products and processes substituted for others which need less material and energy e.g.: from torches, to candles, kerosene lamps, gaslight, incandescent light, fluorescent light to light emitting diodes (LED's). Prices and the market are the drivers behind this mechanism (Cameron and Neal 2003). Moreover more growth also means more resources for research and therefore more technological advances and more substitution.

Factor substitutability, or the substitutability between manmade and natural capital are moreover the basis for the "weak" interpretation of sustainable-development. This is because it implies mechanical reversibility of processes (Söllner 1997), which means that any unfavourable outcome of human activity can be reversed ('technological fix') e.g. ocean fertilization to sequester CO^2 (e.g. Beckerman 1995). Another key assumption of this attitude is the unlimited availability of energy in the future as promised by Nordhaus et al's (1973) 'backstop technology'.

In terms of governance of technology mainstream economists tend to argue that this should be left to market mechanisms, despite the fact, so the critics, that there are numerous examples, where markets chose inferior technological configurations. Technological progress is in this way treated as a single, pre-ordained path; as a 'winner takes all' race along a pre-determined path (Stirling 2007). The rejection of this technological optimism in favour of "prude pessimism" could be seen as the mayor philosophical dividing lines between the mainstream, neoclassical economic theory and Ecological Economics (Costanza 1989)

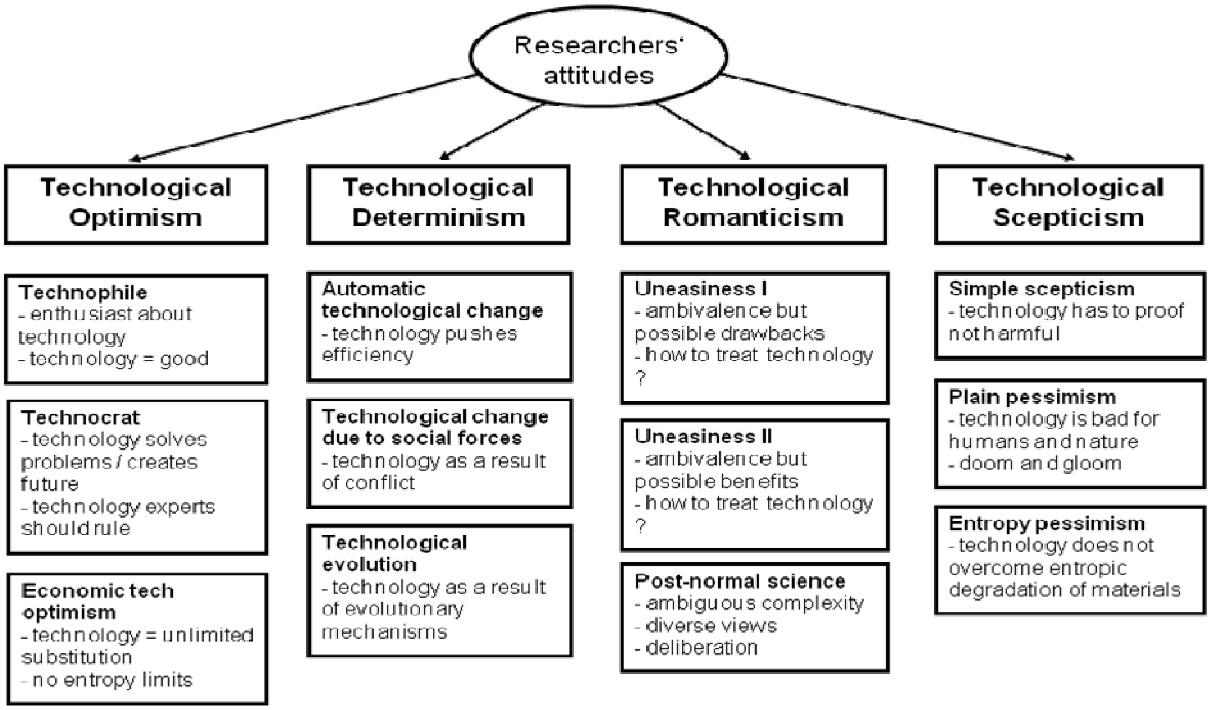

Figure 37: A conceptual frame of attitudes towards technology (ATT)

[Note: During the course of this research effort, we are in the process of expansion and further development of the ATT frameword. See Apendix I of this chapter for a first preview.]

1.6 Material and Methods

The empirical research rests on a case study (Yin 1994) of a two week Marie Curie Summer School in Brighton, which was carried out in June 2009 and focused on “integrated analysis of complex adaptive systems” in the area of ecological economics. Participants were international PhD students and post-docs from the natural and social sciences. Lecturers were international and came from a diversity of backgrounds, ranging from physics to social sciences. The study investigates manifestations of implicit and explicit attitudes towards technology in the teaching and presentation material that was made available to the students. It consists of slides from 17 presentations, which are related to 10 lecturers. The study aims to develop an empirically grounded view on explicit and implicit attitudes towards technology that are conveyed in the presentations. An email questionnaire, consisting of semi-structured and structured questions, has been answered by five lecturers in March 2010 as a complement. It elicits personal and professional backgrounds and aims of the lecturers and also gave them the opportunity to state their personal attitudes towards technology themselves within structured categories based on Figure 37. Answers to semi-structured questions have been condensed inductively to derive codes that enable comparison among individual responses. It was intended to use the resulting data to give reasons of why individual lecturers hold certain attitudes towards technology and convey them in particular ways. But the small sample size and a response rate of 50 per cent requires us to treat the data cautiously.

To conduct a qualitative content analysis of the lecture slides, initial analytical categories were derived from the literature as they are represented in Figure 37 (Mayring 2008). Each category was divided into explicit and implicit contents. Together they formed a basic guideline for finding quotes, statements, assumptions, representations, arguments, *etc.* in the material. The categories were filled up with relevant material from the presentations and the analysis continued with iterative re-elaboration in terms of refinement of contents and categories, adjustment of content-category relation and generalisation of contents with the help of codes derived inductively from the material and deductively from the literature (Miles and Huberman 1994; Mayring 2008). The coding integrated selective, meaningful parts of the material that are of particular significance to our research question (Miles and Huberman 1994). The analysis was conducted jointly. Going through the material yielded explicit definitions and articulation of attitudes, prototypical quotes and rules to distinct among categories, which were reworked and checked in subsequent steps until a more solid picture emerged that is being presented in the results section below.

1.7 Results and discussion

Within the 17 lectures that were analysed, 379 arguments related to technology were identified. All lectures did relate to technology in certain aspects and across lectures the whole range of attitudes described in the literature was covered. However, attitudes towards technology were not always explicitly articulated. Implicit manifestations of attitudes are widespread and also have implications for the general arguments conveyed with a lecture. Thus, the general arguments of a lecture often turn out to be contradictory when taking particular attitudes towards technology articulated within a lecture into account. Generally, individual lectures are skewed towards certain attitudes, although not necessarily intended by the lecturers. The numbers of “techno-arguments” identified in individual lectures differ significantly, partly because the lecture topics imply lesser or more coverage of technology. Another reason may be personal attitudes of lecturers themselves. These might also be reflected in lecture topics. Within individual lectures, though, one has to make a difference, between illustrative repetition of conflicting arguments made by others and those attitudes belonging to the case the lecture is arguing for.

When analysing the content of the lectures, it emerged that optimistic attitudes towards technology were most straightforwardly articulated, while sceptic and ambivalent romantic attitudes were more difficult to trace. Technological determinism can prevail in optimistic and sceptic attitudes, but may also itself be a view on technology. Cases in point are arguments based on concepts of evolution, which often involve technological determinism in ways that prevent direct criticism of underlying statements. Optimism mostly implies determinism, as certain logic is suggested to bring about the desired state of technology. Similar configurations are at work with scepticism, albeit in a different normative direction. In romantic and ambivalent positions, multiple perspectives that share ambiguous views from different, altogether incommensurate, ends prevail. Romantic and ambivalent positions are often unclear about futures and also suggest that views on technology might change in the future, similar as conceived by post-normal science. The boundaries between categories of attitudes are blurry, but optimism is clearly distinct from scepticism. In turn, ambivalent attitudes appeared often close to scepticism, but could not be identified as fully sceptic.

Self-stated attitudes towards technology (T)	Interpretation	Lecturer H	A	J	I	D
a) T is always good	optimist					
b) benefits of T outweigh drawbacks	optimist					
c) T solves problems	optimist	x		x	x	x
d) T expands our limits	optimist	x		x	x	x
e) society always pursues T	determinist	x		x		x
f) T always results in new T	determinist	x		x		x
g) T evolves over time	determinist	x	x	x		x
h) unsure about T, but rather see benefits	romantic					x
i) unsure about T, but rather see drawbacks	romantic			x		
j) society has to deliberate on which T to deploy	PNS view		x	x	x	x
k) T has to prove not being harmful	skepticist		x	x	x	
l) harm caused by T outweighs its benefits	skepticist					
m) T can overcome entropic (physical) limits	entropic optimist	x				
n) T inevitably faces entropic (physical) limits	entropic pessimist		x	x	x	x
Number of statements with attitude towards technology in presentations						
Optimism		13	12	34	-	17
Determinism		2	-	3	1	4
Romanticism		13	5	18	9	1
Scepticism		4	37	5	1	2
Unclear		1	3	-	1	8
Total		33	57	60	12	32

Table (24): Attitudes towards technology as stated by lecturers and aggregated statements containing explicit and implicit attitudes towards technology identified in corresponding lectures.

The email interviews suggest diverse backgrounds and aims of lecturers, which overlap to varying degrees. It seems that their self-stated attitudes towards technology only relate in particular cases to these patterns. For example the two lecturers, who are not involved in environmental issues, claim not to be sceptic about technology. Matching self-stated attitudes towards technology to those found in related lectures seems almost impossible with the data at hand as can be seen in Table (24). Two lecturers, however, did not state clearly determinist attitudes towards technology. In their lectures no or only one determinist position on technology could be found. But these few examples should be treated with caution. Greater sample sizes or deeper interviews should suggest clearer relations. Nevertheless, this is not to say that backgrounds, aims and self-stated attitudes of lecturers should straightforwardly influence the attitudes towards technology conveyed in lectures. More research in this direction would be necessary.

In the lectures were also statements that relate to technology, but lack clarity to which attitudes specifically. A more thorough analysis departing from categorisation of single arguments and using more codes per argument may reveal more insight into both, these statements and the successfully categorised arguments. The categorised arguments, which all convey rather specific attitudes, however, require a more extensive description. Quotes indicate lecturers with a capital letter and lectures with a number starting from one (A1-I1).

1.7.1 Optimism

Optimistic attitudes towards technology were widespread in the lecture material and often clearly articulated. Thus, many arguments are explicit and most arguments can be related to distinctly specifiable subcategories. Optimistic attitudes rest on some sort of improvement by means of technology or a claim that novel and better or optimal technologies are possible. It is partly also emphasised that transfer and diffusion of technology is desirable and possible. The argument then is that technology should be used and that possible limits can be overcome. This assumes that technology can be steered towards desired ends or it is implied that technology will do so by itself or is desirable by any means.

A subcategory of technological optimism claims that technological change is always to the better and consists of improvements to a reference point. In one of the presentations the *"level of technology and innovativeness"* served as a measure of performance (B2). Another (D1) suggested *"niches for radical innovations"* that outperform former innovations. Similar attitudes prevail in graphical representations of technological change where utility derived from technology increases over time, though partly at different rates (B2, C1, D1). Likewise *"economic returns from the use of technology"* and *"incremental improvement"* of technology that are part of a notion of *"technological progress as optimisation"* are mentioned (H1).

A closely related subcategory suggests drawbacks of certain technological advancements, but optimistically it is insisted that there are always possibilities of alternative and better technology. The emphasis is on *"novelty"* (D1, B1) *"innovation"* (B2, D1, E1, J1) and *"alternatives"* (A2, C1, J1) of technology, but also *"learning"* to improve or use technology (D1). Without further specification it is claimed that *"there are many green niche innovations"* and *"windows of opportunity"* for technological novelties (D1).

The optimism that always technology can be found that solves the problems caused by a pre-existent technology rests on notions of repair and reversibility. This subcategory does not abound with arguments, but it contains positions that are straightforward: *"monitor impacts and adjust"* claims one lecture (D1), while another argues that technological diversity does *"mitigate lock-in"* through portfolios that prevent negative pressures to concentrate (J1).

Often attitudes conceive technologies as solving specific problems, without consideration of their wider impacts. Many relating arguments point at responses to climate change. One lecture optimistically suggested that renewable energies are *"good for the environment"*, create employment and are good for coping with peak oil (A2), while another pointed at developing countries' *"access to new technology for economic growth and poverty alleviation"* (F1). Less straightforwardly it was argued that diversity does *"promote resilience"* as it *"offers a 'response' tool for adaptive strategies"* and *"enables experimentation and adaptation to challenge"* (J1).

Cross-cutting through optimistic subcategories are vague and implicit notions of growth and no limits. Some arguments rest on general neo-classic economic optimism or entropy optimism, for example ignoring rebound effects. One lecture identified presumably *"low carbon technology"* such as *"hybrid vehicles"*, *"coal gasification"* and *"improved combustion efficiency"* (F1). Another argued that one needs to *"develop alternative energy sources"*, albeit *"including conservation"* to replace fossil fuels (A2). But further arguments are less explicit when it comes to their relation to entropy and growth, though issues of limits and entropy are actually implied.

1.7.2 Determinism

Three arguments can be associated with technological determinism: (i) technology determining technological change, (ii) technology determining social change, and (iii) society determining technological change. The latter two often come together. For example, a lecture argued that technology affects agents and agents' choices who in turn affect technology (I1). Relating to that, another lecture claimed that *"system evolution is path dependent in that* *choice at one moment in time affects the likelihood of subsequent choices"* (C1). Such evolutionary arguments often contain both deterministic and probabilistic arguments, while the emphasis is on non-random mechanisms. Consequently reinforcement mechanisms are a common theme. One lecturer claimed that *"innovations have historically been clustered in ways that are amplifying"* (H2), while another suggested that *"diffusion is a non-linear process of niche accumulation"* (D1). Similarly deterministic attitudes towards technology appear within technological optimism and scepticism, though these have a positive or negative view on technology.

1.7.3 Romantic uneasiness and post normal science

Attitudes towards technology can have a sense of uneasiness and ambivalence. Many of the arguments in the lecture material turn out multifaceted, because aspects of them could also fall under other attitudes. The ambiguous combination of aspects that also contain elements of uneasiness, however, could better be seen as a specific attitude towards technology. This comes along with notions of complexity, diverse views and possibilities, contingency, uncertainty and limits to settled knowledge, which can mix differently. Thus, decisive prescriptions to treat technology are missing. Tendencies of attitudes can, however, be summarised in subcategories of romantic uneasiness.

An ambivalent attitude towards technology may emphasise possible drawbacks, although no decisive recommendation on how to treat technology is formulated. For example *"winning technology may fail"* over longer terms (D1). Another lecture pointed at different aspects of technology ranging from unproblematic to problematic such as *"risk of engineering failure"*, *"unfamiliar toxins"*, *"hazards 'human factor'"*, *"ambiguity of interests, priorities and framings"*, *"new vectors"* or *"forms of harm"* (J1). Acknowledged difficulties with large-scale change of technology often imply similar uneasiness: a lecture saw *"importance of initial conditions, inability to see the whole map, problems of making the transition"* (H1), while a further claimed that there is no *"silver bullet; all niches have problems, e.g. social debates, resistance, NYMBY"* (D1). Thus, the role of human ambiguity is important and impacts on society are a crucial concern.

To a lesser extent attitudes showed ambivalence towards technology that emphasised a possibility of benefits. Within this subcategory of romantic uneasiness notions of hope coincide with lack of decisive ways to deal with technology. This is exemplified by arguments such as that *"on the whole faster innovation tends to win, but enough time is needed for 'co-evolution'"* (B2). Implicitly ambiguous notions of hope feature in ideas that *"...there is more to the world than human 'feeling' about commodities"* (A2). And, similarly, when claiming that *"rebound effects are significant, but they need not make energy policies ineffective"* (G2) a more materialist notion of hope is being conveyed that is ambiguously embedded.

Attributes of technology that are contingent to changing factors can be an important ingredient of ambiguous and uneasy attitudes towards technology. Within this subcategory of attitudes it remains open whether technology is positive or negative as it is argued explicitly in J1 or that *"resilience as positive or negative depends on object, context, perspective"* (J2). Similarly, due to a probability of being successful or lethal, it is claimed that *"evolution is messy"* (B1). Another lecture identified a *"technical incommensurability"* that relates to *"evolving complex systems, multidimensional nature of complexity"* as well as *"uncertainty, ambiguity and ignorance"* (G3). These examples show that nothing is settled and diverse views are conceivable, which all come with some degree of uneasiness.

Post-normal science (PNS) shares much in common with romantic uneasiness. Lectures did not explicitly suggest a clear boundary between science and technology. But there are many instances where attitudes towards technology would also fit to PNS, in particular when technologies imply problems of uncertainty and ignorance that come along with different views at those problems that nevertheless require evaluation. Attitudes may, thus, emphasise *"indeterminate realities"*, *"reflexive framing"* or *"plural frames"* (J1). Even when knowing an aim, there may be difficulties in achieving it. Accordingly, a lecture suggested an *"incomplete understanding of the technology transfer process"* (F1). Difficulties with objective decision-making are thus often implied.

1.7.4 Scepticism

Critical attitudes towards technology that assume technology causes harm or will be bad under certain circumstances can be summarised as scepticism. Technology thus has to prove not causing harm, while it is generally assumed that technology and its context are unstable. For example, there is a *"fragility of stocks of capital"* and a *"fragility of the entire socio-economic system"* (A1). Degrees of scepticism depend on the contents of arguments. These can be differentiated into specific subcategories. A simple sceptic attitude towards technology can be identified as a subcategory. It implies that unambiguous measurement is possible and risk assessments are needed. Despite partial success of certain technologies, these may fail later, nevertheless. One lecture points at fisheries, where *"the evolution of fleets leads to greater instability"* (B2), while a further lecture suggests a *"shortcoming of the evidence"* that other technologies will be successful (F1). Often, however, scepticism comes close to pessimistic attitudes or even is plain pessimism.

Plainly pessimistic attitudes conceive that technology, over a certain timescale, leads to 'doom'. Collapse is an inevitable outcome and there will be nothing positive afterwards. Use of technology and its effects are thus scary. For example, *"fossil fuel burning is required to stop"*, because of *"catastrophic climate change"*, but *"this is not going to happen"* (A1) and hence the catastrophe is inevitable. Another lecture showed a graph, where negative impacts of economic development are increasing, even if *"clean technology"* is deployed (F1). Such economic-growth criticism forms a special case of pessimistic attitudes, which often relates closely to pessimistic outlooks on entropy developments of the earth. For example, a lecture claims that *"less consumption, more leisure time, will put less stress on the environment"*, that *"we are growing by destroying"* natural capital and that *"people in the future will have fewer economic resources with which to deal with environmental change"* (A1). Correspondingly, *"economics does not provide a map for arriving at a steady state economy"* (H2) and there are notions of the *"economy as an evolving thermodynamic system"* (A1). Relating attitudes that emphasise the rebound effect suggest, even when technology improves efficiency and seemingly breaks thermodynamic limits, the rebound effect would be greater than the savings. It was thus pointed at *"resource efficiency and the rebound effect"*, which imply, directly and indirectly, but also at "economy wide" scales, that *"energy efficiency improvements"* increase demand and thus consumption, therefore drawing down stocks of energy and other resources (G2).

1.7.5 Scope and implications

The analysis of the lecture material yielded a structured account of attitudes towards technology that lecturers implicitly or explicitly conveyed to participants of a summer school. The categorization of attitudes was not always straightforward. Certain overlaps, e.g. between optimism and determinism, have been made clear, but there are at least four issues that require discussion. First, *"transfer and diffusion of technology"* were themes that emerged in various arguments related to different attitudes. One lecture (F1) often linked this to *"technological capacity building"*. Whether or not these terms are jargon, they easily have an optimistic connotation and suggest that technology transfer and diffusion is good. Why else would one care about facilitation of technology transfer and diffusion and why else would *"technological capacity building"* be important? Yet, single arguments were also sceptic on its feasibility. Possibly, therefore, one might construct hierarchies of attitudes towards technology. Second, *"technological transition"* had a similarly optimistic connotation. However, some applications of this term also suggested ambiguous attitudes towards technology and it may well be argued that an inevitability of transitions is deterministic. Third, *"learning"* in relation to technology could be equated with technological advancement. Learning is often about improving technology, being able to create technology or putting technology to optimal use. Rarely, learning seems to be about restricting technological advancement. But sometimes arguments suggested limits to successful learning and knowledge. It is thus unclear how to treat learning and knowledge of technology. The occasionally used term of *"understanding"* still comes with a notion of discovery. It commonly does, however, not presume particular attitudes towards technology. Fourth, the notion of *"technological diversity"* was part of diverse attitudes towards technology, but clearly not related to pessimism. Diversity often had a notion of portfolio optimization that suggests: the more different technologies, the better. Individual technologies may thus not be useful, but at later stages they might be. Hence, diversity often implies attitudes ranging from romantic to optimistic. The concept of technological diversity may also be used strategically and thus implying some sort of optimism, if it for example enlarges possibility spaces of technologies or erodes the control of established technological agendas, because it enables the establishment of an "agenda of alternatives".

Diversity is a concept that could also be applied to the results of the analysis. A diversity of possible attitudes towards technology is evident. Lectures were not clearly biased towards certain attitudes. Rarely, however, sceptic or pessimistic attitudes were critical for the general argument of a lecture. In parts, they might just be a rhetorical device to argue for alternative science, new projects and policy shifts. This would imply optimism, though not necessarily in technological terms and not as a personal value, as certain optimism is often part of applications for research funding. Only problems that can be solved are useful to be worked on. Technology is often suggested to provide such solutions.

Clearly defining technology may thus be important. But in theory this is simpler, as when applying it to the lecture material. Within the material it rather seems that individuals work with different, more or less clearly, defined concepts of technology. In addition, they may not be aware of what attitudes towards technology they exactly convey to others. One may argue for drawing a distinction between science and technology, not only because the lecture material has been produced by scientists. But some scientists may find it useful and others pointless. Possibly the difficulty to establish clear boundaries between applied science and technology boils down to an ethical question of what humans should do to themselves and the material world. Indeed, it is widely held that there is no possibility of value-free definitions of technology (Mitcham 1994). It is thus the “software” part of using and creating technology that needs attention (Rogers 2003: 13). Our data from email interviews, however, suggests that we have to be cautious when predicting attitudes towards technology conveyed in lectures on the basis of personal backgrounds and aims of researchers. Mismatches between self-stated attitudes towards technology and attitudes revealed in lectures do also prevail. Personal background and aims seem very uncertain predictors even of self-assigned attitudes towards technology, which compares to findings on PhD students in ecological economic reported in Ehlers *et al* (2009). But larger sample sizes may help to establish clearer patterns.

The patterns identified in the analysis imply that framings of technology can be diverse and ambiguous. Hence, the framing of attitudes towards technology in this analysis is debatable. Yet, individual attitudes of researchers towards technology might influence research outcomes. At least in parts, these are also embedded in larger paradigms such as unreflective technological optimism. For example, if a study sets out to explore what a future "car-system" might look like, it is implicitly assumed that a system based on individual transport using the automobile is sustainable in the long term, which may not be the case. Even the less optimistic attitudes relating to romantic uneasiness, may turn out as indifferent relations to technology in practice, where there may be a mismatch of attitudes and actual behaviour.

1.8 Conclusions

This study was not an attempt to identify a single correct way to view the role of technology for sustainability. Our goal, instead, was to develop a framework to categorize differing attitudes towards technology and to use it as a tool to make individual stances of researchers and teachers explicit. This is important as positions on technology will inevitably influence the outcomes of sustainability research and teaching. Testing this framework empirically, we conclude that even in a small sample of lecturers working in similar or related disciplines, attitudes towards technology are highly diverse, which is reinforced explicitly and implicitly by the attitudes conveyed in the lectures. Personal backgrounds and aims of researchers and their self-stated attitudes towards technology may not necessarily clearly relate to another and to attitudes conveyed in lectures. While this picture is still unclear, we suspect that such data may only provide limited contributions to transparency of attitudes. But, given the importance of technology in the sustainability discourse, more transparency about the stances on technology that scholars adopt in their research and teaching would be useful. We can only engage in constructive deliberation on the use of technologies, if we know on what attitudes towards technology the relevant research rests. To reflect and to transparently articulate their own attitudes towards technology would in post-normal science terms also be a public responsibility of scientists. Today, technology is increasingly not seen as good per se. Thus, it is argued, that technology should be subjected to some sort of public appraisal. Moreover, there are calls that scientists should be encouraged to clearly expose the limitations and dangers of the new technology they develop or propose. But, as our study shows, there are diverse perspectives on technology. Our framework helps to reveal them as explicit and implicit attitudes towards technology. When deciding on technology deployment it would be fair, if the whole spectrum was brought in and made explicit. There should not be positions or options that are systematically discriminated or ‘closed down’, as it may be suspected in the case of non-adoption of new technologies or a reversal to earlier less advanced practices. Hegemonic discourses on technology may still be at work as these manifest in structures that influence most decision makers. These may be ingrained in personal positions and even dispositions, but may not be made entirely transparent to individual researchers. All, individual attitudes towards technology, discourses and the languages used by researchers require attention when aiming for transparency.

1.9 Acknowledgements

We would like to thank the lecturers of the Themes summer school, in particular Andy Stirling, for responding to our questionnaire and for their support and advice.

1.10 References

Please note references of this article have been integrated in the bibliography of Part 3.

1.11 Appendix I: Updated ATT framework and first reflections

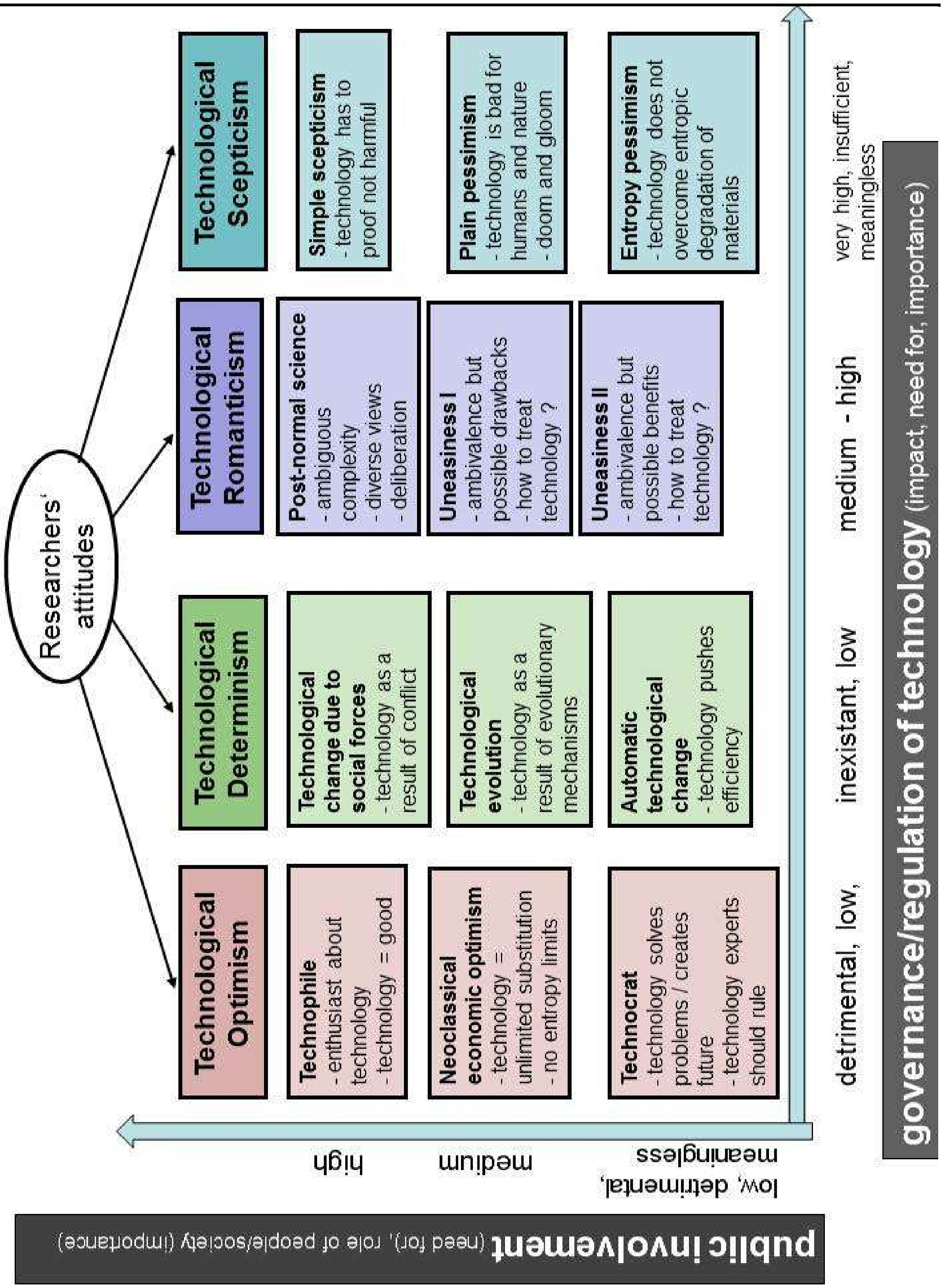

Figure 38: ATT-Framework Updated

Explanation and first reflections:

Two new dimensions have been opened up for the attitudes towards technology spectrum: (1) governance/regulation of technology and (2) public involvement (need for). This is because these two dimensions play a role in all categories.

The Figure is self-evident except for the following: Entropy pessimist score low on both, because the individual is powerless to the laws of entropy and very little can be done by governance (except for limiting resource use). For Romanticists public engagement is not so clear for uneasiness II, but if seen in relation to uneasiness I it is. If technology is rather good there is less need for everybody to get involved. Plain Pessimism: Public engagement may need to be high if the motto is "we all need to fight technology" but on the other hand if all is doom and gloom anyway there maybe little hope.

In any case items should always be seen relative to each other – so it is clearer why there is more public engagement needed for uneasiness I than there is for II.

Taking the governance proposal for technologies from the de-growth conference in Barcelona[111] for example i.e.: selective moratoria for certain (new) technologies - we could say that Optimists would reject that completely, determinists would occasionally agree, Romanticists would probably be just fine with it, while scepticists totally in favour and be very strict (except for the entropy ones who would see it as meaningless – a delusion just like Giampietro (Sorman and Giampietro in press) who argues that "degrowth in general is about trying to plan something that cannot be planned).

[111] http://www.barcelona.degrowth.org/Barcelona-2010-Declaration.119.0.html

2 PAPER IV

Ecological economists' views on technology: an analysis of a survey at the ISEE 2010 conference[112]

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2.1 Abstract

Attitudes of academics towards technology receive little attention, which is regrettable, as attitudes can inform outcomes of teaching and research. They are particularly important for the ecological economics community, because some of them make far-reaching claims about technology. We explore attitudes towards technology, disciplinary backgrounds and views on professional roles and personal aims of participants at the 2010 ISEE conference. Our principal component analysis suggests technological optimism as the dominant paradigm among ecological economists. Although alternative attitudes are generally valued higher, they are much less consistently articulated. Views on society's expectations from their professional roles are much more homogeneous than personal aims. It appears that ecological economists are embedded in institutionalised academic roles, associated with technological optimism and determinism. Ecological economists would need to discuss their alternative views on technology and professional aims much more seriously to bring them to bearing within and beyond their academic community.

2.2 Highlights

- Measures ecological economists' attitudes towards technology and academic practice.
- Technological optimism seems to be the dominant paradigm.
- Alternative views are valued higher than optimism, but much less consistently.
- An open debate about technology and academic practice is still needed.

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2.3 Keywords

Technology, academic practice, attitudes, ecological economics, optimism, paradigm

Abbreviations

ATT-Framework – Attitudes towards technology framework

ISEE – International Society for Ecological Economics

KMO – Kaiser-Meyer-Olkin measure

PCA – Principal Component Analysis

2.4 Introduction

Technology is a recurrent issue in economics and sustainability studies (e.g. Ayres, 2008; Beckerman, 1995; Binswanger, 2001; Cameron and Neal, 2003; Costanza, 1989; Ehrlich and Holdren, 1971; Rosenberg, 1982; Schumacher, 1973; Solow, 1974). It is a declared objective since the very beginning of ecological economics to provide an alternative to the unchallenged technological optimism in neoclassical economic theory (Costanza, 1989), which has been emphasised repeatedly (e.g. Binswanger, 2001; Soellner, 1997). Leading figures in the foundation of ecological economics such as Nicholas Georgescu-Roegen and Kenneth Boulding also expressed strong opinions on technology. The self-declared technological optimist Robert Ayres referred to Georgescu-Roegen as an "entropy pessimist" (Ayres, 2007) because he emphasised the limits of technology (Georgescu-Roegen, 1971). Kenneth Boulding believed that society needs to control technology to avoid unethical usage (Hadjilambrinos 1998). However, among current ecological economics serious reflection on technology appears limited, despite such divergent views on technology within the ecological economics community. Perhaps ecological economists need a clearer map of these views to have an open and fruitful debate.

The basic question is, what is technology for ecological economists? Is it good or bad? Philosophers try to identify the nature and the ends of technology, which appear to fall into a variety of value-laden outlooks (Drengson, 1982; Mitcham, 1994). Technology and science are often used interchangeably in economics, but there are new attempts to explore problems of technology more thoroughly (Faulkner et al., 2010). In science and technology studies there is great emphasis on more fluid social constructions of ontology, ends and impacts of technology (e.g. Bijker, 1995; Jasanoff, 2006; MacKenzie and Wajcman, 1985b; Wynne, 1992). Some implications of such sentiments for ecological economics research are emphasised in the post-normal science (PNS) literature (Funtowicz and Ravetz, 1994), which is also acknowledged in ecological economics. But there is limited empirical research on how ecological economists view technology. Also the implications of views on technology for teaching seem neglected.

We identified patterns of implicit and explicit expressions of attitudes towards technology in the teaching material of a summer school (name deleted to maintain the integrity of the review process). But the explorative study was insufficient to suggest factors that inform teaching and research of ecological economists. Frey et al. (2010) and Mearman (2011) made comparable attempts with statistical analysis of economists' positions on economics. They emphasise a variety of distinct political, theoretical and methodological sentiments, such as divides between monetarists and Keynesian economists.

In this paper we present an initial analysis of a survey at the International Society for Ecological Economics conference in 2010. The survey generates data on personal backgrounds and attitudes towards technology, teaching and research. It enables us to see how far ecological economists agree with certain views on technology and their profession. In particular, we are interested in exploring associations of attitudes towards technology and views on professional practice. Are there consistent perspectives or are the views of ecological economists diverse or even disparate (Stirling, 2007)? For example, ecological economists may greatly value renewable energy, while being pessimistic towards technology in general.

A quantitative survey requires an ordered categorisation of attitudes towards technology, which is then empirically tested. We categorise attitudes towards technology with an attitudes-towards-technology-framework (ATT-framework). The ATT-framework Figure 39 provides a range from blanked optimism towards technology to plain pessimism and rejection of technology. Broad attitudes towards technology can be differentiated into sub-categories. The ATT-framework for a content analysis of teaching material of a summer school and a brief semi-structured email questionnaire answered by five lecturers of the summer school (name deleted to maintain the integrity of the review process). While the framework proves useful, there are some ambiguities of attitudinal categories. Especially attitudes aside from optimism seem difficult to articulate and detect. Distinctions between sceptic and ambivalent attitudes are often less straightforward. However, the email questionnaire suggested diverse, disciplinary backgrounds, aims and roles of researchers and teachers that could correspond with certain attitudes towards technology. Knowledge of these could assist in explaining the prevalence of particular attitudes and behavioural intentions (Ajzen, 1991; Stern et al., 1999). A larger sample could establish clearer patterns of attitudes and their determinants.

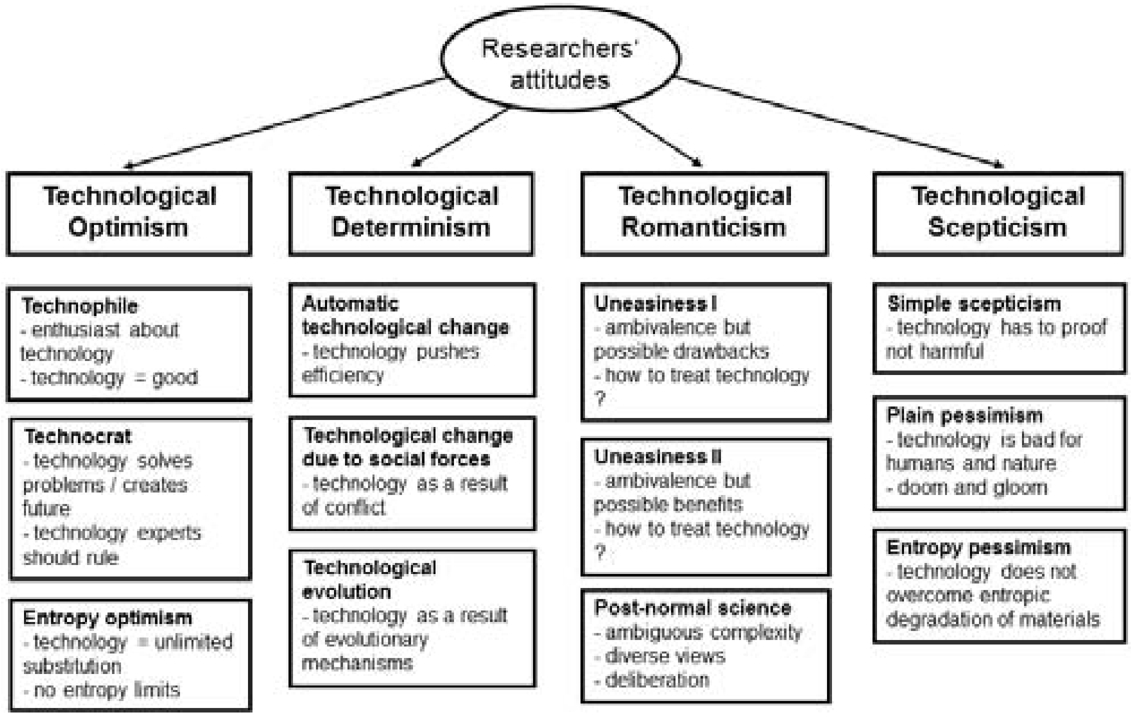

Figure 39: Framework of attitudes towards technology (ATT-Framework).

[Note: During the course of this research effort, we are in the process of expansion and further development of the ATT frameword. See Apendix I of this chapter for a first preview.]

2.5 Material and methods

We use the ATT-framework and the email questionnaire to develop survey items. The final questionnaire for this survey consists of groups of items and open questions. We use Likert scale items (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree), including a “Don’t know” option. These items consist of a) views on different definitions of technology, b) views on personal and professional practice aims, c) views on society's expectations from research and teaching, d) general attitudes towards technology and e) attitudes towards specific technologies. Short open questions capture disciplines of university degrees and methods and theory applied. The questionnaire can be found in appendix A.

All 708 participants of the ISEE 2010 conference, who provided an email address, were asked to complete an anonymous online survey, which was distributed via email. There were 251 responses (35 per cent), of which 184 (26 per cent) are usable for statistical analysis. Such low response is common, but may be an unreliable representation of the ISEE conference. The online survey also implies a self-selection of respondents. Inference to the population of participants of the conference therefore is problematic – even more so to the whole membership of the ISEE. We restrict ourselves to the sample. An extended inference could be made, when the sample has similar patterns as the population of participants (Blaikie, 2003, 167.). The gender composition of 44 per cent female in the population of the conference is reflected in the 45 per cent share in the sample. But shares of nationalities differ greatly. In the population are 42 per cent Germans, while in the sample only 25.5 per cent. The response rates differ greatly among nations. Of Italians 85 per cent responded and of British only eleven per cent. Almost all of the 184 respondents are involved in research (94 per cent) and more than half of the researchers also teach (57.2 per cent). Two respondents only teach and 4.9 per cent of the respondents neither teach nor research. More detailed information on the sample is found in appendix B.

We present descriptive statistics of survey responses. Principal component analysis (PCA) with varimax rotation is used to identify patterns of associated response variables and to reduce them to scales, where feasible. PCA with varimax rotation is a well-established method to construct measurement scales that consist of a set of strongly correlating variables that largely measure the same (Tabachnick and Fidell, 2007, 607-675.), for example technological optimism. The method can also be used to explore patterns in responses to variables that may have an underlying structure, which could be used to explain responses. In this paper we aim at exploration and interpretation of such patterns.

Some open statements of respondents are transformed into single scale items. Statements on applied research methods are scaled from "quantitative" = 1, "mostly quantitative" = 2, "mostly qualitative" = 3 to "qualitative" = 4. Also open statements on disciplinary education are transformed. Undergraduate, postgraduate and doctoral degrees are first related to standard disciplines, taking into account specialist environmentally oriented degrees, such as ecology and environmental engineering. We use the widely applied classification of academic domains of Biglan (1973) to rank the disciplines in 1 to 4 scales in each of the three dimensions of "pure-applied", "hard-soft" and "non-life-life" (Schommer-Aikins et al., 2003). The role of technology in these dimensions could be distinct – technology in engineering may be seen differently as in humanities (Mitcham, 1994). We found the open statements on theories used and the respondents' research areas difficult to classify and do not use them in this analysis.

A one-off PCA on all items as used on views of heterodox economists in Mearman (2011) is not advisable as we investigate conceptually distinct groups of items. We apply PCA to each of the distinct groups of items, with the aim to explore patterns of the responses within these groups and identify groups of interdependent variables in broader dimensions, such as technological optimism or other concepts. Alongside we reduce data of interdependent variables to representative scales. The scales are usable in further analysis that aims to explain attitudes towards technology with the help of personal background variables, somewhat similar to a survey of German economists by Frey et al. (2010). Teaching-related items can require separate analysis as they represent a subgroup in the sample (Hair et al., 2010). The reliability of a PCA depends on ratios of cases to variables, which range from 1: 2 to 1: 25 and are particularly low when including the subpopulation of teachers' responses. Yet, the lowest ratio in our final analysis is 1:5, which is just acceptable (Hair et al., 2010).

2.6 Results

To provide a focal entry to the questionnaire, agreement with three different definitions of technology is measured. Table (25) suggest no great variations in agreement with definitions, although the MacKenzie and Wajcman definition seems to be most preferred. But agreement with the Cambridge definition correlates ($p < 0.01$, Pearson's coefficient 0.211) with the MacKenzie and Wajcman definition to some extent, whereas there is no correlation with the Heidegger definition. These patterns imply confusion or ambiguity among the respondents on what technology could be, which may also be influenced by the authors of a specific definition.

Definition	Mean	Std. Deviation	Skewness
"technology is (the study and knowledge of) the practical, especially industrial use of scientific discoveries" (Cambridge Dictionary, 2010)	2.66	.747	-.250
"technology comprises, first, artifacts and technical systems, second, the knowledge about these and, third, the practices of handling these artifacts and systems" (MacKenzie and Wajcman, 1985a)	3.08	.688	-.532
"the manufacture and utilisation of equipment, tools, and the machines, the manufactured and used things themselves, and the needs and ends they serve, all belong to what technology is" (Heidegger, 1977)	2.77	.764	-.418

Table (25): Agreement with definitions of technology (1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree).

2.6.1 Analysis of attitudes towards technology

All 22 items on attitudes towards specific technologies and technology in general are initially taken together with the item that measures interest in technology. The descriptive statistics in Table (26) show a great variation in valid responses (mean = 161, standard deviation 14.6). Numbers of valid responses tend to increase with agreement with statements (Pearson's r = 0.36), exceptions being the items "Nuclear power" and "Nanotechnology". Items such as "Nanotechnology" or "Harm of technology outweighs benefits" may have a low N, because respondents do not have a clear opinion on them or are deliberatively avoiding an opinion. The full scale from totally disagreeing to totally agreeing is covered. Only heart pacemakers and organic farming did not encounter total disagreement among respondents. Nuclear power is seen less promising, whereas organic farming, wind turbines and heart pacemakers are considered very promising. There is also large agreement with the post normal science positions that technology should be seen in context and society should deliberate about technology. Related, there are sceptic attitudes, which expressed the need for technology to prove its harmlessness. This appears straightforward. But there tends to be stronger agreement that technology will face physical limits, while it also tends to be agreed that technology expands limits. The position that technology evolves over time tends to be agreed with rather low standard deviation. This position can perhaps accommodate many perspectives.

Item	Valid N	Mean	Std. Deviation	Skewness
Interested in technology	175	2.94	.696	-.225
Technology is good	142	2.58	.718	-.101
Technology is generally good	155	2.72	.826	-.213
Benefits of technology outweigh drawbacks	135	2.67	.743	.074
Technology solves problems	161	2.90	.691	-.557
Technology expands limits	172	3.07	.663	-.442
Societies inevitably pursue technology	169	2.95	.726	-.391
Technology always results in new technology	159	2.82	.710	.171
Technology evolves over time	173	3.29	.570	-.473
Unsure about technology, but rather see benefits	168	2.63	.626	-.411

Unsure about technology, but rather see drawbacks	161	2.35	.584	.138
Technology should be seen in its particular context	177	3.42	.635	-1.032
Society should deliberate about technology deployment	165	3.36	.699	-.856
Technology has to prove that it is not harmful	173	3.32	.707	-.855
Harm of technology outweighs benefits	132	2.30	.761	.481
Technology inevitably faces physical limits	158	3.37	.662	-.702
Nuclear power	171	1.78	.851	.721
Wind turbines	177	3.34	.582	-.395
Genetically modified crops	155	1.95	.907	.619
Heart pacemakers	154	3.31	.554	-.025
Organic farming	174	3.53	.555	-.627
Nanotechnology	130	3.00	.807	-.539

Table (26): Agreement with general views on technology and the promise of specific technologies (1 = totally disagree, 2 = disagree, 3 = agree, 4 = totally agree). Dashed lines indicate different groups of items according to the ATT-Framework.

A PCA of all 22 items on attitudes towards technology has a "middling" Kaiser-Meyer-Olkin measure of 0.735 (Kaiser and Rice, 1974) and shows 6 distinct factors that describe 66 per cent of the variance after factor rotation. It is questionable, whether the item "Interested in technology" should be included, as it conceptually does not measure specific attitudes towards technology directly and the item loads to greater extents on three different factors. Table (27) presents results without the item "Interested in technology". Only Factor 1 can be used as a reliable scale, as Cronbach's alpha is sufficiently high. Factor 1 covers positive attitudes and the promise of “riskier” or more controversial technologies. It also includes an inevitable social pursuit in technology. Factor 2 tends to disregard expansion of limits and emphasises sceptical and pessimist attitudes. Factor 3 covers the promise of wind turbines and organic farming, including the position that it should be deliberated about technology. Factor 4 encompasses technological determinism and evolution and the promise of heart pacemakers. Factor 5 concerns contextual deliberation about technology, which inevitably faces physical limits. Factor 6 rather sees benefits in technology, but is otherwise unsure, while it suggests that technology does not have to prove its harmlessness. Results are not clear-cut, except for the first factor and for Factors 3 and 4, which include special technologies. The more positive views on technology seem much more consistently correlated than critical and ambiguous attitudes, which also have low item-to-total correlations. It can imply that the items measure other variables or that respondents interpreted them inconsistently (Blaikie, 2003, 217.). These results suggest that a common language on critical and ambiguous attitudes may be lacking and that strict criteria have to be set for constructing scales that measure broader attitudes towards technology.

	Factor[a]						Item-to-total
Item	1	2	3	4	5	6	correlations
Technology is good	.737						.469
Technology is generally good	.746						.577
Benefits of technology outweigh drawbacks	.690						.488
Technology solves problems	.751						.601
Technology expands limits	.585	-.501					.482
Societies inevitably pursue technology	.496						.467
Technology always results in new technology				.749			.335
Technology evolves over time				.672			.482
Unsure about technology, but rather see benefits						.770	.080
Unsure about technology, but rather see drawbacks		.766					-.185
Technology should be seen in its particular context					.727		.003
Society should deliberate about technology deployment			.596		.562		.067
Technology has to prove that it is not harmful		.520				-.513	-.007
Harm of technology outweighs benefits		.759					-.202
Technology inevitably faces physical limits					.645		.185

Nuclear power	.839						.621
Wind turbines			.749				.284
Genetically modified crops	.706						.522
Heart pacemakers				.605			.332
Organic farming			.837				.121
Nanotechnology	.622						.520
Eigenvalue	4.829	2.373	2.114	1.766	1.665	1.340	
Variance (%)	22.995	11.302	10.068	8.412	7.930	6.383	
Cronbach's alpha	.890	.227	.521	.459	.297	-.124	.748

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 1. Kaiser-Meyer-Olkin measure: 0.731. Bartlett's tests of sphericity : Approx. Chi-square 531.636 (p = 0.000).

Table (27): Rotated factor matrix on general and specific attitudes (factor loading of at least 0.5) with item-to-total correlations for individual items, excluding item "Interest in technology".

Specific technologies may be better treated separately. An analysis of the promise of specific technologies, suggest two distinct factors with "mediocre" sampling adequacy (Table (28)). Factor 1 covers technologies that imply traditional notions of progress and are sometimes seen risky. Factor 2 covers alternative technologies and the rarely disputed heart pacemaker, but with lower scale reliability.

	Factor[a]		Item-to-total
Item	1	2	correlation
Nuclear power	.886		.499
Wind turbines		.689	.285
Genetically modified crops	.849		.497
Heart pacemakers		.719	.243
Organic farming		.729	.139
Nanotechnology	.758		.602
Eigenvalue	2.117	1.617	
Variance (%)	35.281	26.944	

Cronbach's alpha	.779	.557	.651

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 1. Kaiser-Meyer-Olkin measure: 0.644. Bartlett's tests of sphericity: Approx. Chi-square 126.698 (p = 0.000).

Table (28): Rotated factor matrix on the promise of specific technologies (factor loading of at least 0.5) with item-to-total correlations for individual items.

The outcome of a similar analysis of all items on general attitudes towards technology depends on whether the item "Interested in technology" is included or not. In both cases the first two factors are rather distinct. One is representing optimistic attitudes and the other deterministic attitudes. The remaining three factors have a less clear pattern. The clearest picture emerges, when setting the initial eigenvalue at 0.8 (Table (29)). Factor 1 is robustly covering optimistic attitudes towards technology and Factor 2 is less robustly covering deterministic views on technology. Factor 3 focuses sceptic views on technologies including to some extent the need for deliberation on technology deployment. The latter is also emphasised in Factor 4, which is particularly concerned with a need to see technology in context, but scale reliability is poor. Factor 5 covers ambiguous views on technology, but has poor scale reliability. Only Factor 1 should be used as a scale, while Factor 2 may be cautiously used. In summary, the analysis suggests that agreement with optimistic attitudes towards technology is consistently correlating and could even include the promise of specific technologies that are often seen risky. There is also some consistency among deterministic attitudes. Pessimistic, sceptic and post-normal science attitudes appear less consistent. The leading paradigm seems to be technological optimism associated with determinism, against which other attitudes may be measured. Low item-to-total correlations suggest great confusion concerning non-optimist attitudes. It appears much more difficult to have positions on non-optimistic attitudes, although these tend to be agreed to greater extents than optimistic attitudes. The view that technology faces physical limits appears to have its own niche.

	Factor[a]						Item-to-total
Item	1	2	3	4	5	6	correlation
Technology is good	.647						.347
Technology is generally good	.755						.501

Benefits of technology outweigh drawbacks	.762						.423
Technology solves problems	.867						.492
Technology expands limits	.735						.377
Societies inevitably pursue technology		.655					.415
Technology always results in new technology		.834					.408
Technology evolves over time		.566					.395
Unsure about technology, but rather see benefits					.894		.076
Unsure about technology, but rather see drawbacks					.606		-.038
Technology should be seen in its particular context				.714			.018
Society should deliberate about technology deployment			.504	.645			-.074
Technology has to prove that it is not harmful			.795				.103
Harm of technology outweighs benefits			.639				-.178
Technology inevitably faces physical limits						.869	.156
Eigenvalue	3.467	1.684	1.668	1.426	1.245	1.094	
Variance (%)	23.115	11.225	11.117	9.508	8.302	7.294	
Cronbach's alpha	.837	.597	.527	.305	.106	-	.588

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 0.8. Kaiser-Meyer-Olkin measure: 0.765. Bartlett's tests of sphericity: Approx. Chi-square 349.646 (p = 0.000).

Table (29): Rotated factor matrix on general attitudes towards technology (factor loading of at least 0.5) with item-to-total correlations for individual factors.

2.6.2 Analysis of disciplinary backgrounds

Disciplinary backgrounds of ecological economists can be diverse and there may be linkages between disciplines as classified by Biglan (1973), research practices and attitudes towards technology (Mitcham, 1994). Hard disciplines, such as engineering and chemistry may rely rather on quantitative methods and are closer to hard technology. Sociology and political science, instead, lack common paradigms and also use more flexible qualitative methods (Schommer-Aikins et al., 2003). Additionally, it could be that more applied disciplines and life sciences use particular methods that are used less in pure and non-life disciplines. According to Biglan (1973), non-life disciplines are interested in non-living subject matters, such as geology, whereas life disciplines are interested in living subject matters, such as biology and societies. Our scale with equal intervals to describe methods from quantitative (1) to qualitative (4) may, however, be inappropriate as mixed methods and pure methods cannot be compared this way.

A summary of individual university degrees of the ISEE respondents is found in appendix B. Table (30) suggests that quantitative methods tend to dominate among them, although there is a great spread. Also Mearman (2011) observed that ecological economists enjoy modelling and maths. In our sample there is, however, a shift to softer disciplines with higher university degrees. Bachelor degrees tend to be less applied. Throughout disciplinary careers the non-life-life dimension appears rather stable. But larger standard deviations at initial stages suggest a greater spread within the dimension, which could suggest that there are distinct mechanisms at work, which shape careers of ecological economists or that changes in higher education regimes had an impact.

Item	Valid N	Mean	Std. Deviation	Skewness
Bachelor hard-soft	109	2.53	.929	-.272
Bachelor pure-applied	109	2.28	.682	.645
Bachelor non-life-life	109	2.57	1.003	.172
Master hard-soft	142	2.75	.792	-.834
Master pure-applied	142	2.71	.830	.284
Master non-life-life	142	2.65	.792	-.064
PhD hard-soft	120	2.92	.544	-1.018
PhD pure-applied	120	2.65	.774	.258
PhD non-life-life	120	2.65	.644	.093
Method	170	2.26	.914	.391

Table (30): Disciplinary characteristics of university degrees and methods used (1 = very hard, very pure, very non-life, quantitative; 2 = hard, pure, non-life, mostly quantitative; 3 = soft, applied, life, mostly qualitative, 4 = very soft, very applied, very life, qualitative).

A principle component analysis yields distinct scales that explain 68.9 per cent of the variation in disciplines (Table (31)). While sampling adequacy is just acceptable, the loading of factors has a clear pattern. The PhD items load not very heavily on factors 1 and 2, which suggests that moves to softer(harder) or more non-life(life) disciplines are more common after master degrees. Factor 1 seems to be much more reliable scale than the other factors. There is a rather strong correlation of the "PhD pure-applied" item with the "Method" item, which suggests a consistent correlation of PhD foci with research methods used. The "Master pure-applied" has a low item-to-total correlation, which may be due to specialist and multidisciplinary master degrees that are difficult to classify. Factor 1 could be used as a scale, which measures degrees to which PhDs are applied together with the degree that methods are quantitative. Such a scale could be related to attitudes towards technology. Factor 2 may only be very cautiously used, when exploring the relations of disciplinary dimensions to attitudes towards technology more generally.

	Factor[a]				Item-to-total
Item	1	2	3	4	correlation
Bachelor non-life-life	.834				.605
Master non-life-life	.832				.590
PhD non-life-life	.681				.469
Bachelor hard-soft		.801			.475
Master hard-soft		.789			.465
PhD hard-soft		.578			.347
PhD pure-applied			.843		.449
Master pure-applied			.787		.103
Method			.644		.603
Bachelor pure-applied				.875	-
Eigenvalue	2.1	1.9	1.8	1.1	
Variance (%)	21.1	18.8	18.0	11.0	

Cronbach's alpha	.707	.586	.493	-	.505

[a] Principal component analysis and varimax rotation with Kaiser Normalisation. Kaiser-Meyer-Olkin measure: 0.555. Bartlett's test of sphericity: Approx. Chi-square 144.22 (p = 0.000).

Table (31): Rotated factor matrix (factor loading of at least 0.5) on disciplinary background with item-to-total correlations for individual factors.

2.6.3 Views on professional practice and personal aims

Depending on understanding of teaching and research aims and roles, attitudes towards technology may be conveyed implicitly in professional practice. Our analysis of professional practice views in teaching suffers low N values. Teaching can, however, be seen as a subset of researching. Overall, valid N tends to increase with higher agreement on items (Pearson's r = 0.82 to 0.92). Table (32) shows, that there is no total disagreement with several aims items and no disagreement at all with the aim “Equip students with skills & knowledge”. Income-earning aims received low agreement for both teaching and research, although standard deviations are rather high. The personal aim of “Having a successful career” received comparatively low agreement and has a low valid N. Respondents may not like the question or are unsure about their own aspirations. There is strong agreement with more altruistic research aims and more educational teaching aims. Altruism extends into the private sphere, but to “Enjoy life” is also strongly agreed. There seems more disagreement with the aims “Minimize teaching time” and to “Impress students with my knowledge”, which has a larger standard deviation. Overall, agreement with particular teaching and research aims greatly differs. A question then is how certain aims are associated with certain attitudes towards technology. For example, knowledge may be conveyed to students and society with an undercurrent of pessimistic or optimistic attitudes towards technology (name deleted to maintain the integrity of the review process).

Items	Valid N	Minimum	Mean	Std. Deviation	Skewness
Research aims:					
Improve human well-being	163	2	3.52	.548	-.541
Contribute to scientific knowledge	167	2	3.50	.569	-.608
Help solving problems	165	2	3.53	.525	-.366
Have fun	156	1	3.11	.715	-.700

Publish important work	153	1	3.08	.703	-.456
Understand questions	166	2	3.44	.617	-.628
Challenge current affairs	157	1	3.39	.658	-.904
Earn an income (research)	154	1	2.74	.721	-.411
Teaching aims:					
Encourage critical thought (aim)	100	2	3.73	.468	-1.350
Equip students with skills & knowledge	99	3	3.56	.499	-.227
Increase students' subject interest	96	2	3.46	.560	-.383
Minimize teaching time	88	1	1.98	.678	.481
Earn an income (teaching)	87	1	2.69	.767	-.666
Impress students with my knowledge	86	1	1.79	.813	.808
Increase/maintain own skills & knowledge	98	1	3.16	.714	-.771
Personal aims:					
Keep learning	174	2	3.77	.449	-1.677
Make a difference	170	1	3.36	.658	-.664
Be good to others	160	1	3.39	.645	-.734
Be physically fit	163	1	3.12	.636	-.399
Have a successful career	154	1	2.96	.656	-.383
Enjoy life	170	2	3.62	.523	-.863

Table (32): Agreement with potential professional and personal aims (1 = totally disagree, 2 = disagree, 3 = agree, 4 = totally agree).

Table (33) suggests that views on society's expectations from research as perceived by the researchers themselves tend to match research aims. Although generally agreed, there is much less agreement that society expects researchers to "Publish" and to "Be critical of current affairs". But "Publish" has a rather great standard deviation and "Be critical of current affairs" has a rather low valid N. There is large agreement that society expects teaching to "Convey knowledge" and also expects teachers to "Encourage learning". Teaching to increase the employability of students is also a very much agreed. Expectations from teaching are generally viewed the "Same as a researcher", but vary greatly and N is low. Overall, it is viewed that society expects unambiguous benefits from teaching and research and does not share much the academic world's obsession with publishing.

Item	Valid N	Mean	Std. Deviation	Skewness
Expectations from research:				
Be innovative	161	3.34	.689	-.783
Provide evidence	159	3.40	.628	-.714
Contribute to problem solving	167	3.48	.619	-.921
Improve human well-being	159	3.31	.638	-.533
Publish	154	2.76	.825	-.092
Be critical of current affairs	150	2.98	.764	-.332
Expectations from teaching:				
Convey knowledge	99	3.57	.574	-1.252
Form active participants of society	93	3.10	.738	-.487
Explain social values to students	92	2.79	.778	-.049
Encourage learning	94	3.36	.620	-.702
Same as a researcher	81	2.52	.853	.251
Increase employability of students	96	3.26	.653	-.554
Encourage critical thought (society)	93	3.03	.840	-.511

Table (33): Agreement with potential expectations of society from research and teaching (1 = totally disagree, 2 = disagree, 3 = agree, 4 = totally agree).

Personal aims cannot necessarily be separated from professional aims and practice expectations. A PCA with varimax factor rotation and initial eigenvalues of at least 1 reduces the 34 items on professional practice to 11 factors but has an "unacceptable" Kaiser-Meyer-Olkin (KMO) value of 0.154 (Kaiser and Rice, 1974). The value is increased to a "miserable" 0.583, if only aims items are considered. But the factor loading is not clear-cut. When only research and private aims are considered, the KMO value increases to 0.664 and 5 factors explain 63 per cent of the variance. Certain items may have to be excluded from the analysis at the outset and teaching items may be better considered separately. Looking only on research and personal aims, the KMO increases to 0.694, if item "Challenge current affairs", which greatly diminishes scale reliability, is taken out. The rotated factors have a clear pattern, but factor loading is often low (Table (34)). Factors 1, 2 and 3 may be used cautiously as scales. Overall, however, association of personal aims and research aims items appears week, which suggests that the selected personal aims could only inform research aims inconsistently and to limited extend.

	Factor[a]					Item-to-total
Item	1	2	3	4	5	correlation
Improve human well-being			.756			.319
Contribute to scientific knowledge		.866				.361
Help solving problems			.587			.429
Have fun			.515	.540		.434
Publish important work		.693				.435
Understand questions				.821		.211
Earn an income (research)	.595					.331
Keep learning			.620			.341
Make a difference					.857	.271
Be good to others	.539					.450
Be physically fit	.768					.481
Have a successful career	.557	.				.512
Enjoy life	.504			.626		.406
Eigenvalue	2.126	1.92	1.771	1.500	1.296	
Variance (%)	16.356	14.768	13.621	11.537	9.969	
Cronbach's alpha	.612	.584	.595	.516	-	.758

[a] Principal Component Analysis and varimax rotation with Kaiser Normalization and initial eigenvalues at 0.9. Kaiser-Meyer-Olkin measure: 0.694. Bartlett's tests of sphericity: Approx. Chi-square 295.183 (p = 0.000).

Table (34): Rotated factor matrix on research and personal aims (factor loading of at least 0.5) with item-to-total correlations for individual items, excluding item "Challenge current affairs".

A PCA of the teaching and personal aims items, uncovered "Impress students with my knowledge" as an item that inflicts negative average covariance in a factor. The factor analysis without the item leads to partly clear-cut patterns, with a “miserable” KMO (Table (35)). As personal aims and teaching items tend to load on different factors they could also be treated separately.

	Factor[a]					Item-to-total
Item	1	2	3	4	5	correlation
Keep learning					.879	.172
Make a difference	.765					.282
Be good to others	.761					.418
Be physically fit	.764					.574
Have a successful career			.659			.571
Enjoy life				-.686		.216
Encourage critical thought (aim)						.255
Equip students with skills & knowledge		.761				.302
Increase students' subject interest		.772	.502			.436
Minimize teaching time			.700	.		.216
Earn an income (teaching)			.728			.206
Increase/maintain own skills & knowledge				.735		.153
Eigenvalue	2.036	1.785	1.615	1.416	1.245	
Variance (%)	16.970	14.876	13.458	11.799	10.379	
Cronbach’s alpha	.569	.644	.561	-.071	-	.677

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 1. Kaiser-Meyer-Olkin measure: 0.569. Bartlett’s tests of sphericity: Approx. Chi-square 144.569 (p = 0.000).

Table (35): Rotated factor matrix on teaching and personal aims (factor loading of at least 0.5) with item-to-total correlations for individual items.

An analysis of teaching aims items only and without the ambiguous item "Impress students with my knowledge", has almost "mediocre” sampling adequacy and a clear pattern of rotated factor loading, when the initial eigenvalue is 0.9 (Table (36)). The item-to-total correlations are rather poor. But Factor 1 is comparatively solid and focuses on subject-related skill and knowledge development of students, which is also conceptually straightforward.

Item	Factor[a] 1	2	3	Item-to-total correlations
Encourage critical thought (aim)		.732		.187
Equip students with skills & knowledge	.912			.291
Increase students' subject interest	.750			.474
Minimize teaching time			.762	.154
Earn an income (teaching)			.797	.235
Increase/maintain own skills & knowledge		.814		.223
Eigenvalue	1.429	1.300	1.293	
Variance (%)	23.808	21.665	21.543	
Cronbach's alpha	.644	.215	.419	.490

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 0.9. Kaiser-Meyer-Olkin measure: 0.590. Bartlett's tests of sphericity: Approx. Chi-square 42.400 (p = 0.000).

Table (36): Rotated factor matrix on teaching aims (factor loading of at least 0.4) with item-to-total correlations for individual items.

A similar factor analysis of personal aims only, has a "mediocre" sampling adequacy (Kaiser and Rice, 1974) though the item "Have a successful career" loads to limited extent on both factors (Table (37)). Factor 1 has rather robust scale reliability. It concerns mainly being physically fit, whilst enjoying life and also being good to others. But the patterns seem less straightforward and the second factor is very week.

Item	Factor[1] 1	2	Item-to-total correlation
Keep learning		.669	.240
Make a difference		.761	.312
Be good to others	.607		.423
Be physically fit	.782		.525

Have a successful career			.349
Enjoy life	.749		.266
Eigenvalue	1.749	1.380	
Variance (%)	29.148	22.995	
Cronbach's alpha	.614	.311	.621

[1] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 1. Kaiser-Meyer-Olkin measure: 0.673. Bartlett's tests of sphericity: Approx. Chi-square 84.076 (p = 0.000).

Table (37): Rotated factor matrix on personal aims (factor loading of at least 0.4) with item-to-total correlations for individual items.

When looking at research aims only, the item "Challenge current affairs" could be included, as it does not diminish consistency. The results are fairly clear and largely consistent with the outcome when taking research and personal aims together, but sampling adequacy is poor (Table (38)). The factors may only be cautiously used as scales. Overall the analysis of personal and professional aims suggests that research and teaching aims are only loosely associated with personal aims. But having a successful career, for example, relates to some extent to instrumental teaching aims and to publishing important work. Aims seem to be relatively inconsistent among the respondents and it appears doubtful whether there could be more general patterns in relation to attitudes towards technology. But this does not exclude the presence of very specific relations between two variables.

	Factor[a]				Item-to-total
Item	1	2	3	4	correlation
Improve human well-being	.732				.263
Contribute to scientific knowledge		.879			.335
Help solving problems	.718				.287
Publish important work		.723			.311
Understand questions			.695		.251
Earn an income (research)				.803	.279
Have fun	.652				.404

Challenge current affairs			.741		.214
Eigenvalue	1.598	1.571	1.313	1.024	
Variance (%)	19.980	19.641	16.412	12.799	
Cronbach's alpha	.537	.584	.407	-	.589

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 0.9. Kaiser-Meyer-Olkin measure: 0.576. Bartlett's tests of sphericity: Approx. Chi-square 110.403 (p = 0.000).

Table (38): Rotated factor matrix on research aims (factor loading of at least 0.4) with item-to-total correlations for individual items.

The items on the respondents' views on society's expectations from teaching and research are generally more consistent. But there are only 60 valid cases, which could be increased to 72, if the research items are treated separately. A PCA with initial eigenvalues of at least 1 reduces the 13 items on views on society's expectations from research and teaching to 4 factors that explain 70 per cent of the variance with a "meritorious" KMO (Kaiser and Rice, 1974) of 0.813. But the item "Publish" could be excluded as it has a loading of 0.968 on the fourth factor, on which no other item loads more than 0.25. Without the item "Publish" three factors are separated (Table (39)). Factor 1 emphasises encouragement of critical thought and learning and forming students that are active participants of society through explanation of social values, whilst as researcher one is expected to be critical of current affairs. Factor 2 focuses on the delivery of knowledge in teaching, while contributing to problem solving through provision of evidence and being innovative as a researcher, which to some extent also implies improvement of human well-being. Factor 3 is less clear, much weaker and has low item-to-total correlations, especially for "Increase employability of students". The factors mix expectations from research and teaching in particular patterns, which could be associated with particular attitudes towards technology. But these patterns would only count for those, who both teach and research. It would be interesting to see, how they compare to patterns that can be found separately within teaching or research expectations. If there are distinct patterns in teaching and research expectations only, they may be related to certain attitudes towards technology, which differ between teaching and research.

Item	Factor[a] 1	2	3	Item-to-total correlations
Be innovative		.668		.620
Provide evidence		.809		.467
Contribute to problem solving		.776		620
Improve human well-being		.558		682
Be critical of current affairs	.689			.523
Convey knowledge		.840		546
Form active participants of society	.791			.626
Explain social values to students	.637		.521	.652
Encourage learning	.649			.586
Same as a researcher			.676	.381
Increase employability of students			.721	.324
Encourage critical thought (society)	.904			.613
Eigenvalue	3.195	3.039	1.713	
Variance (%)	26.623	25.327	14.275	
Cronbach's alpha	.842	.836	.543	.866

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 1. Kaiser-Meyer-Olkin measure: 0.838. Bartlett's tests of sphericity: Approx. Chi-square 313.564 (p = 0.000).

Table (39): Rotated factor matrix on views on society's expectations from research and teaching (factor loading of at least 0.5) with item-to-total correlations for individual items.

A PCA of all items on expectations from research, including the problematic item "Publish" has a "middling" (Kaiser and Rice, 1974) sampling adequacy (Table (40)). Factor 1 has high scale reliability and emphasises views that society expects provision of evidence and contribution to problem solving, while also being innovative. Factor 2 should be treated with caution and focuses on the view that research should challenge current affairs and improve human wellbeing. The item "Publish" could be used instead of Factor 3 and suggests that publishing has little to do with the other expectations.

Item	Factor[a] 1	2	3	Item-to-total correlations
Be innovative	.610			.565
Provide evidence	.878			.424
Contribute to problem solving	.807			.552
Improve human well-being		.748		.486
Be critical of current affairs		.870		.365
Publish			.985	-.031
Eigenvalue	1.916	1.633	1.031	
Variance (%)	31.926	27.210	17.191	
Cronbach's alpha	.704	.563	-	.632

[a] Principal Component Analysis and varimax rotation with Kaiser Normalisation and initial eigenvalues at 0.9. Kaiser-Meyer-Olkin measure: 0.715. Bartlett's tests of sphericity: Approx. Chi-square 172.671 (p = 0.000).

Table (40): Rotated factor matrix on views on society's expectation from research (factor loading of at least 0.5) with item-to-total correlations for individual factors

A factor analysis of all items on expectations from teaching shows a "middling" KMO. But the rotated factor loading, which leads to two factors, is less clear-cut. The item "Increase employability of students" has by far the highest loading on factor two (0.931), while "Convey knowledge" and "Same as researcher" load to similar extents on both factors. It may be better to exclude the items, together with "Increase employability of students", which has a poor item-to-total correlation and therefore unique. The result is a single factor with consistently high loading and a "meritorious" KMO value (Table (41)). The factor covers 84 cases and can be used as a scale that emphasises the education of critically learning and socially active students, while the excluded items capture separate views on expectations from teaching that could be related separately to attitudes towards technology.

Item	Factor[a] 1	Item-to-total correlation
Form active participants of society	.883	.774
Explains social values to students	.816	.669
Encourage learning	.759	.597
Encourage critical thought (society)	.863	.734
Eigenvalue	2.767	
Variance (%)	69.175	
Cronbach's alpha	.849	.849

[a] Principal Component Analysis with initial eigenvalues at 1. Kaiser-Meyer-Olkin measure: 0.803. Bartlett's tests of sphericity: Approx. Chi-square 143.245 (p = 0.000).

Table (41): Factor on views on society's expectation from teaching (factor loading of at least 0.4) with item-to-total correlations.

2.6.4 Summary of factors and scales

A number of factors are extracted that can be used as scales. But many items are still to be used individually. Some insights on association of variables are gained, however, including those that are not part of robust factors. Table (42) and Table (43) summarise all sufficiently robust scales and those that may be used cautiously. There are some overlaps of items in scales.

Scale	Item	Item-to-total correlation	Alpha if item excluded	Alpha
Specific techno optimist	"Technology is good"	.646	.878	
	"Technology is generally good"	.666	.876	
	"Benefits of technology outweigh drawbacks"	.632	.879	
	"Technology solves problems"	.795	.866	.890
	"Technology expands limits"	.639	.878	
	"Societies inevitably pursue technology"	.533	.886	
	"Nuclear power"	.691	.874	

	"Genetically modified crops"	.618	.881	
	"Nanotechnology"	.619	.879	
Specific technology deliberation[a]	"Society should deliberate about technology deployment"	.310	.482	.521
	"Wind turbines"	.318	.448	
	"Organic farming"	.394	.342	
Specific technology determinism[a]	"Technology always results in new technology"	.324	.291	.459
	"Technology evolves over time"	.348	.258	
	"Heart pacemakers"	.196	.493	
Specific "risky" technology	"Nuclear power"	.671	.639	.779
	"Genetically modified crops"	.620	.698	
	"Nanotechnology"	.563	.757	
Specific "nice" technology[a]	"Wind turbines"	.353	.482	.557
	"Heart pacemakers"	.346	.489	
	"Organic farming"	.407	.397	
Technological optimist	"Technology is good"	.620	.809	.837
	"Technology is generally good"	.638	.806	
	"Benefits of technology outweigh drawbacks"	.640	.803	
	"Technology solves problems"	.755	.770	
	"Technology expands limits"	.551	.826	
Technological determinism[a]	"Societies inevitably pursue technology"	.427	.467	.597
	"Technology always results in new technology"	.418	.479	
	"Technology evolves over time"	.389	.533	
Technological scepticism[a]	"Society should deliberate about technology deployment"	.308	.477	.527
	"Technology has to prove not harmful"	.356	.400	
	"Harm of technology outweighs benefits"	.355	.399	

[a] Scale to be used cautiously.

Table (42): Scales on attitudes towards technology (alpha = Cronbach's alpha).

Scale	Item	Item-to-total correlation	Alpha if item excluded	Alpha
Discipline non-life-life	"Bachelor non-life-life"	.605	.556	
	"Master non-life-life"	.590	.541	.707
	"PhD non-life-life"	.469	.705	
Discipline hard-soft[1]	"Bachelor hard-soft"	.475	.414	
	"Master hard-soft"	.462	.391	.586
	"PhD hard-soft"	.347	.585	
Income for person aim[a]	"Earn an income (research)"	.255	.621	
	"Be good to others"	.365	.558	
	"Be physically fit"	.564	.447	.612
	"Have a successful career"	.345	.568	
	"Enjoy life"	.332	.576	
Knowledge publishing aim[a]	"Contribute to scientific knowledge"	.423	-	.584
	"Publish important work"	.423	-	
Subject skill provision aim	"Equip students with skills & knowledge"	.479	-	.644
	"Increase student's subject interest"	.479	-	
Personal goodness aim	"Be good to others"	.416	.528	
	"Be physically fit"	.507	.381	.614
	"Enjoy life"	.359	.600	
Research for well-being aim[a]	"Improve human well-being"	.371	.407	
	"Help solving problems"	.382	.405	.537
	"Have fun"	.324	.516	
Research for science aim[a]	"Contribute to scientific knowledge"	.423	-	.584
	"Publish important work"	.423	-	
Critical academic role	"Be critical of current affairs"	.554	.835	
	"Form active participants of society"	.726	.788	.842
	"Explain social values to students"	.641	.811	

	"Encourage learning"	.579	.828	
	"Encourage critical thought (society)"	.749	.779	
Providing academic role	"Be innovative"	.622	.809	
	"Provide evidence"	.623	.808	
	"Contribute to problem solving"	.728	.777	.836
	"Improve human well-being"	.573	.821	
	"Convey knowledge"	.655	.801	
Providing researcher role	"Be innovative"	.489	.661	
	"Provide evidence"	.544	.588	.704
	"Contribute to problem solving"	.537	.595	
Human researcher role[a]	"Improve human well-being"	.396	-	.563
	"Be critical of current affairs"	.396	-	
Engaged educator role	"Form active participants of society"	.774	.770	
	"Explain social values to students"	.669	.817	.849
	"Encourage learning"	.597	.846	
	"Encourage critical thought (society)"	.734	.788	

[a] Scale to be used cautiously

Table (43): Scales on disciplinarity and aims and views in academic practice (alpha = Cronbach's alpha).

Table (44) and Table (45) provide descriptive statistics of all sufficiently robust scales and those that may be used cautiously. "Riskier" or more controversial technologies are seen less promising, while alternative and not generally contested technologies are evaluated positively. This reflects some optimism towards technology in general. But the weaker scepticism scale has slightly higher agreement. Optimism is associated with minor agreement in "riskier" technologies. Alternative "nice" technologies on the other hand are seen more promising and they are associated with a strong desire to deliberate about technologies in context. Yet, technology is generally seen from deterministic or evolutionary perspectives, which our analysis cannot clearly differentiate. Conceptually, however, it is also not always clear, to what extent technological evolution is deterministic (Pfaffenberger, 1988; Smith and Marx, 2001). Despite these patterns, there are contradictions, which could rest on certain classes of respondents with certain backgrounds, whose positions on technology differ.

Scale	Valid N	Minimum	Maximum	Mean	Std. Deviation	Skewness
Specific techno optimist	76	1.11	4.00	2.71	.601	-.254
Specific technology deliberation[a]	155	2.33	4.00	3.41	.443	-.465
Specific "risky" technology	114	1.00	4.00	2.31	.733	.288
Specific "nice" technology	149	2.33	4.00	3.41	.415	-.238
Technological optimist	111	1.20	4.00	2.76	.584	.030
Technological determinism[a]	147	1.00	4.00	3.04	.506	-.067
Technological scepticism[a]	117	1.33	4.00	2.97	.538	-.133

[a] Scale to be used cautiously

Table (44): Descriptive statistics of scales on attitudes towards technology (1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree).

Scale	Valid N	Minimum	Maximum	Mean	Std. Deviation	Skewness
Discipline non-life-life	68	1.33	4.00	2.66	.665	.230
Discipline hard-soft[a]	68	1.33	3.67	2.72	.538	-.619
Income for person aim[a]	120	2.20	4.00	3.18	.398	-.052
Knowledge publishing aim[a]	150	1.50	4.00	3.31	.536	-.501
Subject skill provision aim	95	2.50	4.00	3.51	.455	-.301
Personal goodness aim	150	2.33	4.00	3.39	.458	-.365
Research for well-being aim[a]	146	2.00	4.00	3.40	.434	-.319
Research for science aim[a]	150	1.50	4.00	3.31	.536	-.501
Critical academic role	75	1.20	4.00	3.09	.587	-.637
Providing academic role	79	1.00	4.00	3.41	.510	-1.525
Providing researcher role	151	1.00	4.00	3.41	.517	-1.068
Human researcher role[a]	145	1.00	4.00	3.16	.591	-.487

Engaged educator role	84	1.00	4.00	3.10	.622	-.544

[a] Scale to be used cautiously

Table (45): Descriptive statistics of scales on disciplinarity and aims and views in academic practice.

Table (45) suggests groupings of professional and private background aims and perceived roles of respondents, with partly distinct levels of agreement. But the general patterns in background seem more fine-grained and thus also potential associations with attitudes towards technology. The scales on disciplinary background tend to have values in the middle range and only suggest that there is a slight tendency towards life and soft disciplines among the ecological economists. Instead of using such aggregates it may be worthwhile to relate individual disciplines to attitudes towards technology.

There is great agreement with roles and aims of research and teaching to provide evidence, knowledge and skills. Agreement with a narrow aim of knowledge production in publications is also strong. To a lesser extent criticism and socially oriented education are also expected. The patterns of associated aims items are less clear, than those of roles. Perhaps social roles mediate personal and professional aims or the phrasing of aims items has been more challenging, though this could effectively mean the same in a quantitative survey.

Attitudes towards technology could be influenced by values of background scales, as our previous research suggests (name deleted to maintain the integrity of the review process). Table (46) provides simple correlations for the most robust scales. Despite the separation into scales with distinct underlying structures through principal component analysis, all scales on personal and academic practice aims and perceptions of roles correlate significantly with each other, particularly with the “Providing academic role”. All these scales positively support each other at least weakly, with some strong correlations among them. But the relations of these scales to scales that measure attitudes towards technology can be distinct and strengths of correlations with scales of attitudes towards technology vary greatly. A clear-cut pattern emerges from the observation that specific “nice” technology does not correlate with technological optimism. Among the attitudes towards technology there is a strong positive correlation of technological optimism with specific “risky” technology, which suggest that the support of such technologies requires strong technological optimism. How promising alternative “nice“ technologies are seen correlates weakly with the “Subject skill provision aim”, which, in turn, might be related to certain non-life disciplines. Among the scales on personal and academic practice aims and perceptions of roles, the personal aims scale (c) does not correlate strongly with any attitude towards technology. All scales on society's expectations (roles) (d, e, f, g) correlate positively with technological optimism, though weakest with the "Providing researcher role" (f). Correlations with critical roles (d) seem to differ not much from provision-oriented roles (e, f). But the rather strong correlations with "risky" technology are more significant with critical academic roles (d) and socially engaged roles (g) of educators. It suggests that the ecological economists' agreement with such roles that challenge society tends to come along with support of riskier technology. The "Providing academic role", however, correlates strongly positive with the integrative scale of "Specific techno optimist". The patterns of correlations of all these scales are not always straightforward and we have to note that mean agreement with most of the scales is close to indifference, while specific "nice" technology has strong support (see Table (44)). Overall, it seems, however, that strong correlations are also a reflection of rather clear-cut paradigms of technological optimism, of socially engaged education and research, and of unidirectional knowledge flows from science to society.

Scale	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)
a) Discipline non-life-life										
b) Subject skill provision aim	**-.306**									
c) Personal goodness aim	.134	**.295***								
d) Critical academic role	-.031	**.283***	**.296***							
e) Providing academic role	.223	**.242***	**.439*****	**.528*****						
f) Providing researcher role	**.260**	**.223***	**.264****	**.457*****	~~.962***~~					
g) Engaged educator role	.075	**.228***	**.364****	~~.976***~~	**.524*****	**.460*****				
h) Specific techno optimist	.202	.115	.093	**.441****	**.506****	**.348****	**.407****			
i) Specific "risky" technology	.240	.038	.024	**.463*****	**.308***	**.224***	**.445*****	~~.882***~~		
j) Specific "nice" technology[a]	.153	**.257***	.161	.126	.192	.141	.112	.123	.150	
k) Technological optimist	.025	.081	.034	**.350***	**.352***	**.276****	**.309***	~~.935***~~	**.691*****	.117

*p<0.05, **p<0.01, ***p<0.001, [a]scale less robust.

Table (46): Pearson's correlation of sufficiently robust scales on attitudes towards technology and aims and views in academic practice (correlations of at least 0.25 in bold, correlations of scales sharing items are crossed out).

2.7 Discussion

Our analysis yields a more general overview of attitudes towards technology and of aims and views on social roles among a group of ecological economists. We focus on descriptive statistics and underlying patterns in sets of variables to construct scales and to examine whether certain attitudes towards technology and aims and views on roles are consistently associated. A further interpretation of possible influences on attitudes towards technology and aims and views on roles would require a closer look at both, scales and individual variables. There could be predictors of particular attitudes towards technology among the constructed scales. The scales of “Specific “risky” technology” and “Technological optimism” seem to represent certain attitudes very well. Explanation could also be extended with demographic variables including nationalities, which would enable a comparison with larger surveys on related topics such as the Eurobarometer on science and technology (European Commission, 2010). Of greater theoretical and practical value, however, could be the prediction of relationships of attitudes with views on professional practice and disciplinary education, as it is within such areas, where technological values can be transmitted (Ambrose, 2006; Ylijoki, 2000).

The framing of technology appears to be a difficult issue for researchers and teachers in ecological economics, at least in our sample. Technological optimism seems a consistent paradigm on which clear opinions can be articulated. The ecological economists in our sample are cautiously optimistic about technology in general and very optimistic about specific alternative technologies such as organic farming. Specific technologies that are commonly seen as riskier are consistently not found promising. More sceptical and critical perspectives on technology in general are, however, much less consistently articulated. Although seeing technology in context is greatly favoured, this is not closely associated with sceptical attitudes. The value of seeing technology in context and deliberating about technology appears to be either superficial or intrinsic, without association with other attitudes, which suggests that the ecological economists only consider parts of the Post-Normal Science positions put forward in ecological economics (Funtowicz and Ravetz, 1994). It could also imply that context itself is seen as the appropriate valuation framework (Flyvbjerg, 2001), when other concepts like technological optimism are disregarded. But even in such context it may be much easier to articulate attitudes that are measured against a consistent technological optimism, which the ecological economists of our sample easily frame. The articulation of sceptic and ambiguous voices, in turn, would be more cacophonic, when they cannot be contrasted with optimism. Should ecological economists aim at changing perspectives on technology, it seems promising to more thoroughly engage in mainstreaming contextualism and scepticism instead of simply disagreeing with technological optimism.

Professional roles and aims of our ecological economists appear problematic in several respects. Most importantly self-prescribed roles as society's expectations from professional practice are much more consistently evaluated than personal aims in professional practice of teaching and research. This could simply suggest that individuals are more diverse and complex than their social roles. Professional norms and expectations could mediate personal desires. Clear perspectives on social roles also imply that these can be related more generally to attitudes towards technology, while it is more difficult with professional aims. More socially engaged teaching and critical research roles and roles of linear knowledge production and dissemination all correlate strongly with optimistic attitudes towards technology, despite conceptual contradictions between criticism and linear knowledge production. It could be that these positions rest on more established paradigms. Alternative perspectives and personal and professional aims seem to have more complex patterns and lack underlying paradigms. The greatly acknowledged physical limits to technology are, for example, not closely associated with other views. This could suggest that our ecological economists are embedded in institutionalised academic roles, associated with technological optimism and determinism. Hence escaping this nexus could be difficult. But both incremental and sudden reframing of particular technologies seems possible (Geels and Schot, 2007). Organic farming and wind energy, for example, are consistently highly valued and have only recently gained some dominance, though it may be argued that this still rests on technological optimism.

Our analysis remained descriptive and exploratory. In many cases more robust claims cannot be made. Instead of generalising variations and explanations across the sample, in future studies we may also identify typical cases within the sample using cluster analysis (Mearman, 2011) or latent class analysis. This would assume the possibility of distinct types of academics in the sample. Already at this stage, however, we can provide a structured overview of a sample of ecological economists and encourage reflection. The principal component analysis is successful in detecting patterns in the variations of parts of the data, while particularly aims of our ecological economists tend to be inconsistently correlated with one another. Aims may thus be poorly reflected in their community and especially in their professional practice. In this sense, a bold claim could be that ecological economics is without a soul, because the members of the community do not translate their aims into their work. However, some robust scales on aims can be constructed and could be used in further explanatory analysis. It also appears that the principal component analysis can identify dominant paradigms in views on technology and academic practice. The analysis presented here can be a first step towards the mapping and explanation of attitudes towards technology in academic practice based on personal and professional background. The insights can be used to reflect on teaching and research practice and possible intervention to gear teaching and research towards desired ends. Overall, it appears that ecological economists failed to deliberate technological values more thoroughly among themselves. Concepts of technology's wider implications and the practical bearings of alternative attitudes towards technology could still become much clearer, when more ecological economics researchers and practitioners put them under serious scrutiny and debate. Else, ecological economists would be less likely to jointly contribute to alternative views and practice in teaching and research.

2.8 Acknowledgements

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2.9 References

Please note references of this article have been integrated in the bibliography of Part 3.

2.10 Appendix A: Online Questionnaire

Attitudes towards technology

We put the brief questionnaire together, because we are interested in the following questions:

What attitudes towards technology prevail among researchers and teachers, who work on issues related to sustainability?

In what contexts do particular attitudes towards technology prevail?

Welcome and thank you for your interest in our questionnaire. It will take you about 5 to 15 minutes. The data will be treated fully confidential and will be used exclusively in our own research project on the role of technology in sustainability research and teaching. This project does not have external funding. You will be able to receive our research results, if you sign up with your email address in the online survey or if you contact us directly per email.

START

Technology Definition:

1. Do you agree with the following definitions of the term "technology"?

a) technology is …"(the study and knowledge of) the practical, especially industrial, use of scientific discoveries" (Cambridge online dictionary),

Totally agree/agree/disagree/totally disagree (don't know)

b) "technology comprises, first, artifacts and technical systems, second, the knowledge about these and, third, the practices of handling these artifacts and systems" (MacKenzie and Wajcman 1985)

Totally agree/agree/disagree/totally disagree (don't know)

c) "The manufacture and utilisation of equipment, tools, and machines, the manufactured and used things themselves, and the needs and ends they serve, all belong to what technology is" (Heidegger 1977)

Totally agree/agree/disagree/totally disagree (don't know)

d) I prefer my own definition which is: (medium textbox)

Teaching and Research:

2. In what subjects have you been educated?

Bachelor (small textbox)

Masters (small textbox)

PhD / Doctorate (small textbox)

3. What topical areas do you work on?

a) (small textbox)

b) (small textbox)

c) (small textbox)

Please provide the 3 most important for you e.g. ecosystem services, climate change, social metabolism, green accounting, etc.

4. What research methods do you use?

a) (small textbox)

b) (small textbox)

c) (small textbox)

Please provide the 3 most important for you, e.g. econometrics, input-output analysis, multi-criteria appraisal, qualitative case studies, field experiments, ecological modelling, quantitative surveys, etc.

5. What theories do you use?

a) (small textbox)

b) (small textbox)

c) (small textbox)

Please provide the 3 most important for you, e.g. behavioural economics, evolutionary economics, discourse theory, theory of planned behaviour, public choice theory, political ecology, etc.

I conduct/undertake research. YES/NO (if YES, then questions 6 and 9 are added)

6. Which aims do you follow with your research? (Totally agree/agree/disagree/totally disagree (don't know))

a) To improve human well-being.

b) To contribute to scientific knowledge.

c) To help solving problems.

d) To have fun.

e) To publish important work.

f) To understand questions.

g) To challenge the current state of affairs.

h) To earn an income.

i) I follow aims in my research that are not listed above. They are: (medium text box)

Are involved in teaching? YES/NO (if YES, then questions 7 and 10 are added)

7. Which aims do you follow in your teaching? (Totally agree/agree/disagree/totally disagree (don't know))

a) Encourage critical thought.

b) Equip students with skills and knowledge.

c) To increase students' interest in a subject.

d) To minimize the time teaching takes away from research.

e) To earn an income.

f) To impress students with my knowledge.

g) Increase or maintain my own skills and knowledge.

h) I follow aims with my teaching which are not listed above. They are: (medium text box)

8. Which personal aims do you have? (Totally agree/agree/disagree/totally disagree (don't know))

a) To keep learning.

b) To make a difference.

c) To be good to others.

d) To be physically fit.

e) To have a successful career.

f) To enjoy life.

g) I have personal aims, which were not listed above. They are: (medium text box)

9. What do you think society expects from you as a researcher? (Totally agree/agree/disagree/totally disagree (don't know))

a) To be innovative.

b) To provide evidence.

c) To contribute to problem solving.

d) To improve human well-being.

e) To publish.

f) To be critical of current affairs.

g) I think there are other things society expects from me as a researcher, which were not listed before. They are: (medium text box)

10. What do you think society expects from you as a teacher/lecturer? (Totally agree/agree/disagree/totally disagree (don't know))

a) To convey knowledge.

b) To form active participants of society.

c) To explain social values to students.

d) To encourage learning.

e) The same as a researcher.

f) To increase the employability of students.

g) To encourage critical thought.

h) I think there are other things society expects from me as a teacher, which were not listed before. They are: (medium text box)

11. I am very interested in technology. (Totally agree/agree/disagree/totally disagree (don't know))

12a. Do you agree with the following attitudes towards technology (Part I)? (Totally agree/agree/disagree/totally disagree (don't know))

a) Technology is good.

b) Technology is generally good.

c) The benefits of technology outweigh its drawbacks.

d) Technology solves problems.

e) Technology expands our limits.

f) Human societies inevitably pursue technology.

g) Technology always results in new technology.

h) Technology evolves over time.

12b. Do you agree with the following attitudes towards technology (Part II)? (Totally agree/agree/disagree/totally disagree (don't know))

i) I am unsure about technology, but rather see its benefits.

j) I am unsure about technology, but rather see its drawbacks.

k) One should see a technology in its particular context.

l) Society (including lay people) should deliberate about which technology to deploy.

m) Technology has to prove that is not harmful (to humans and nature).

n) Harm caused by technology (to humans and nature) outweighs its benefits.

o) Technology inevitably faces physical limits.

13) If you would like to comment on the previous two questions, please use the box below. (medium text box)

14. The following technologies are promising in my opinion.* (Totally agree/agree/disagree/totally disagree (don't know))

a) Nuclear power.

b) Wind turbines.

c) Genetically modified crops.

d) Heart pacemakers.

e) Organic farming.

f) Nanotechnology.

* Promising for the favourable advancement of the human society.

15. If you find other technologies particularly promising or if you would like to comment on the previous question please use the box below. (medium text box)

16. Demographical data

a) Please indicate your gender (female, male)

b) Please indicate your age (list with ranges)

c) Please indicate your nationality (list with nationalities)

d) Please indicate approximately the number of inhabitants of the settlement where you live. (list with ranges)

e) Please indicate the number of children under 18 years of age in your household. (list with numbers 0 to 10)

f) Are you married or do you have a partner for more than 5 years? (yes, no)

g) Please indicate the type of organisation you work for. (list with university, public research institute, public administration, private company, NGO, foundation, consultancy, other (small textbox))

17. If you have any additional comments on our survey, please indicate them below. (large textbox)

Please sign up here, if you wish to be informed about our results (confidential).

EXCELLENT!!! Thank you very much for completing our questionnaire. Please don't hesitate to contact us directly if you have any comments, questions or suggestions.

Submit your survey.

Thank you for completing this survey.

2.11 Appendix B: Background of Respondents

Disciplines	Bachelor (n)	Master (n)	PhD (n)
Total	109	142	120
Agricultural Economics	-	5	3
Agriculture	5	5	2
Anthropology	3	-	-
Biology	11	6	2
Chemistry	1	-	-
Computer Science	-	1	-
Development Studies	-	3	2
Ecological Economics	-	5	13
Ecology	8	5	4
Economics	33	32	34
Engineering	7	7	-
Environmental Economics	-	10	10
Environmental Engineering	4	6	6
Environmental Management	6	16	10
Environmental Science	3	-	-

Forestry	3	3	1
Geography	3	5	3
Languages	3	-	-
Law	1	1	-
Management	5	10	6
Mathematics	4	1	1
Philosophy	1	1	2
Physics	-	2	1
Planning	1	4	2
Political Science	4	12	3
Resource Economics	-	-	5
Sociology	3	2	6
Sustainable Development	-	-	4

Table B.1: Disciplines of university degrees of the respondents.

Number of inhabitants	Frequency (%)
countryside	.5
below 100	1.6
100 – 1,000	1.6
1,000 – 10,000	4.3
10,000 – 100,000	14.1
100,000 – 500,000	25.0
500,000 – 1,000,000	14.7
1,000,000 – 5,000,000	26.6
5,000,000 – 10,000,000	2.7
above 10,000,000	5.4
no response	3.3

Table B.2: Settlements where respondents reside (N = 184).

Type of organisation	Frequency (%)
University	75.0
Public research institute	21.7
Public administration	2.7
Private company	6.5
Non-governmental organisation	3.8
Foundation	2.2
Consultancy	4.3
Other	4.9

Table B.3: Organisations, where respondents work (N = 184).

	Age (years)					
Gender	20 - 30	31 - 40	41 - 50	51 - 60	above 60	Total
Female (%)	43.4	32.5	15.7	8.4	0.0	45.4
Male (%)	30.0	38.0	17.0	9.0	6.0	54.6
% of total	36.1	35.5	16.4	8.7	3.3	100.0

Table B.4: Gender and age of respondents (N = 183, one missing).

	Number of children					
Married	0	1	2	3	4	Total
Not married (%)	94.4	5.6	0.0	0.0	0.0	42.1
Married (%)	48.5	25.3	22.2	3.0	1.0	57.9
% of total	67.8	17.0	12.9	1.8	0.6	100.0

Table B.5: Marital status and number of children of respondents (N = 171, rest missing).

3 Concluding Remarks and Outlook – De-growth and Technology

Part 3 of this Thesis was motivated by the fact that no discussion about Peak-Oil or generally about our sustainability predicament will be able to avoid the question about the potentials of future technologies (in particular energy technologies). As one stakeholder in a process in relation to macroeconomic resilience (Kerschner 2012) stated: "You cannot have a sustainability debate anywhere, without people getting out their favourite miracle energy solution to all problems." Hence the goal of the above stream of research is to encourage an open debate about attitudes towards technology.

A critical self-reflection requires us to uncover, recognize and discuss the full range of possible attitudes. Post-normal science literature (e.g.: Stirling 2008) puts great emphasis on such contingencies. To paraphrase Latouche, what is needed is a decolonization of our imaginaries about technology. Only then can we embark on a process to open up the debate over technological options (rather than closing it down). A clearer perspective of possible attitudes towards technology may help to ignite such processes.

Providing the link to the following chapter, it has to be stressed that the way our society sees and relates itself to technology is crucial for the debate on economic degrowth. Latouche and others have recognized this and propose, a highly critical if not pessimist attitude, which goes back to Georgescu-Roegen (e.g.: 1976) but more importantly to Ivan Illich (1973). This diversion from the dominant paradigm of unquestioned technological optimism within the wider degrowth community was well illustrated by the radical call for selective moratoria on new technologies at the 2010 Barcelona degrowth conference. In a future paper in this ATT series, we will argue that in the absence of critical self-reflection, the community may easily find itself having replaced the dominant "techno-optimist" – dogma, with a "techno-pessimist dogma". But there are many other possible attitudes towards technology.

4 References – Part 3

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PART 4 [Paper V]

De-growth and the Steady State Economy: Exploring radical Policy Options

1 Introduction – Part 4: The Steady State Economy: The only path to a sustainable future?

1.1 Abstract

Ecological Economists (e.g.: Herman Daly) claim that sustainable development can only be achieved by drastically changing our growth based economic system. Continuous economic growth, which is the goal of every government, is inherently incompatible with sustainable development, unless sustainable development is defined in a weak sense; that is as accepting substitutability between human made and natural capital. This is currently done by neoclassical economic theory, the roots of which are based on a value concept, analogous with the conservation principle of classical mechanics. Some authors argue that it is this value concept combined with the panacea of technological progress, which allows neoclassical economic theory to believe in unlimited economic growth.

Not only is continuous economic growth physically impossible (i.e.: the dematerialisation hypothesis is a myth), given Georgescu-Roegen's interpretations of the laws of thermodynamics, but also undesirable. Various studies (e.g.: calculations of the Index of Sustainable Economic Welfare) suggest that the actual wellbeing of the human society is not increasing, but in fact decreasing with further growth of the economy.

The alternative to growth or decline is the steady state. Most classical economists acknowledged the existence of a steady state, including Adam Smith, Thomas Malthus, Karl Marx and John Stuart Mill. They all had their own ideas about such a state; some equated it with disaster, others glorified it. However, most of them had a positivistic concept of such a state.

Herman Daly supports Mill's view of a positive i.e.: inevitable, but also normative steady state. He believes that humanity would be well advised to bring about a steady state economy (SSE) before it is forced upon it. Daly offers a theoretically simple political framework, which could be used for such a goal. Three institutions are to be employed to stabilise the system at a constant level. The first one would be in charge of stabilising the human population, which is inevitable. The second institution introduces depletion quotas, which are auctioned by the government, in order to reduce material and energy throughput. Finally a distributionist

institution ought to secure social justice by introducing minimum and also maximum income limits.

Obviously this is a very controversial concept and has been mostly ignored by fellow scientists or rejected as utopia. Robert Ayres argues that given enough energy, which could be generated by finding new ways to capture the abundant solar rays, almost anything could be recycled, allowing for even more economic growth. There are many flaws within Daly's ideas and there are issues, which are not discussed (e.g.: imports, expropriation of the rich, entrepreneurial incentives). One important aspect is whether the functioning of the capitalist system could be maintained in a steady state. Mill, Marx, Schumpeter and Keynes, all implicitly assumed that a steady-state economy would be equal to socialism (or at least the end of capitalism).

Nevertheless these flaws in Daly's SSE concept do not justify a rejection of his approach and of the steady state as such, but should give rise to the development of other concepts or suggestions for its improvement. The sustainability discourse cannot and should not ignore the concept of a steady state.

1.2 Introduction

At least since the Brundtland Commission's Report (WCED 1987), *sustainability* and *sustainable development* are buzzwords among politicians and within international institutions. The very meaning of these words and their implications however, remain ambiguous to date. In fact it is supposed that the only reason why there is such widespread support for the sustainability concept is that it has been left rather vague by the authors (Costanza, Norgaard et al. 1997). Neither did the Brundtland Commission distinguish between strong and weak sustainability, nor did they point in anyway towards the sharp conflict between sustainability and growth.

Since the earth is finite and non-growing, any physical subsystem must also eventually become non-growing. It follows that economic growth and sustainable development are incompatible. The former refers to a quantitative expansion in the scale of the physical dimension of an economic system, while the latter should refer to the qualitative change of a physically non-growing economic system in dynamic equilibrium with the environment

(Costanza, Norgaard et al. 1997). The modern ‘growth debate’[113] is however much older than the Brundtland Report. The influential report to the Club of Rome, *The Limits to Growth*, by Meadows et al. (1972), predicted an imminent depletion of natural resources, using an integrated world model. Even earlier than that some authors pointed to the limits imposed by the second law of thermodynamics for economic systems (Boulding 1966; Georgescu-Roegen 1971).

The aim of this paper is firstly to analyse the origins of what will be referred to as, the ‘growth paradigm’. Then the physical possibility and socio-ethical desirability of continuous economic growth will be further discussed. The two final parts of this paper will then present the steady state economy (or stationary economy), as the only sustainable alternative to the growth economy. After looking at the theoretic history of this alternative concept, Herman Daly’s (1992a) visionary institutions for bringing about a steady state are presented and critically analysed.

1.3 The growth paradigm and its theoretical background

Economics began as a branch of moral philosophy, where the ethical content was at least as important as the analytical, up to the writings of Alfred Marshall (Brandis 1989). Marshall’s *Principles of Economics* (1890) established neoclassical economic theory as the mainstream economic theory. From then on, so Daly (1992a, p 3), “(...) *the structure of economic theory became more and more top-heavy with analysis. Layer upon layer of abstruse mathematical models were erected higher and higher above the shallow concrete foundation of fact.*“

Stanley Jevons (1835 –1882) suggested renaming what was then called *Political Economy* into *Economics* and the change of words was coupled with the most important paradigm shift in theoretic economic history. It brought about a „destruction of the classical system“ (Schumpeter 1970 [1908]) with far reaching consequences. Motivated by the successes of the natural sciences, in particular physics and classical mechanics, efforts were undertaken to establish economics as a more scientific subject. This was a direct result of an influential philosophical movement of the 1920s and early 1930s, called *logical positivism*. It originated from the Vienna Circle, a group of loosely knit philosophers, led by Moritz Schlick (Okasha 2002).

[113] The ‘growth debate’ itself probably goes back to the writings of Thomas Malthus in the 18th century.

Culminating with Marshall's Principles (1890) economics gradually adopted a mechanistic philosophy in the period between 1870 and 1939 (Wiener 1966).The field theory of value, which is based on the energy field of classical mechanics became the core of neoclassical economic theory. Therein value is equated with utility and thus no longer resides in the goods, but in the mind of the individual (i.e. peoples preferences) (Söllner 1997). The resulting human behavioural goal of maximising utility also originates in the analogy between energy and utility. From this moment normative concepts became exogenous to economic theory, ethical issues were now a matter of personal taste and economics emerged as the simple "mechanics of utility and self-interest" (Jevons 1924). Economists fully embraced "the mechanistic, reductionistic and positivistic mode of thought" (Daly 1992a, p. 20) at the time. The consequences were far-reaching, in particular with respect to the position of the ecosystem relative to the economy.

Even today the Economy is often portrayed as a closed, isolated system in economic textbooks, similar to a clockwork (Georgescu-Roegen 1971), or the circular flow model depicted in Figure 40 (Daly 1996; Martínez-Alier and Roca 2000). Hence there are no inflows from and outflows to the environment. The supply of natural resources and the capacity to absorb waste are therefore not perceived as limiting factors for economic development. However in the late 60's early 70's, environmental problems became more and more evident and this economic model was challenged, probably most famously by Boulding's (1966) concept of ‚*spaceship earth*' and the *Limits to Growth* by Meadows et al. (1972) The response to these developments was the creation of the sub-discipline of environmental economics, but it was built upon the same foundations, i.e. the energy analogy, as neoclassical economics and is therefore affected by the same shortcomings (Söllner 1997).

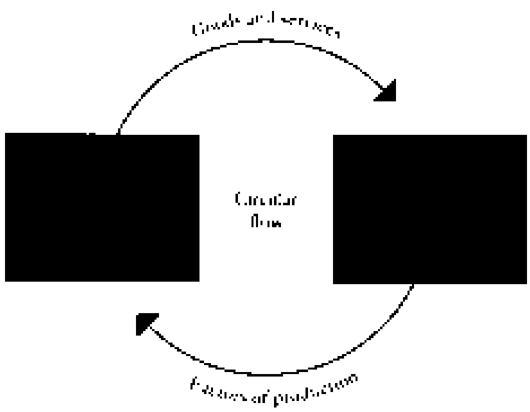

Figure 40: The economy as an isolated system (taken from: Daly 1996, p. 47)

Firstly resources are assumed, in principle, to be substitutable without restrictions. Although this might be true for some goods and raw materials, it is ridiculous to assume for example that copper could ever substitute rice in the human diet. Nevertheless orthodox economists (e.g.: Barnett and Morse 1963) reject the concept of *absolute scarcity* advocated by Daly (1992a) , to them resources are only scarce relative to another resource, or a different (lower) quality of the same resource. Relative scarcity can be overcome by substitution, whereby relatively abundant resources are eventually substituted for relatively scarce ones. Resources are therefore unlimited in total and merely non-homogenous in quality. Advances in science and technology are supposed to overcome this obstacle by making them more homogenous.

According to Daly (1992a) *ultimate means* in the form of low entropy matter/energy are scarce in an *absolute* sense i.e. there are absolute limits beyond which availability is nil. The allocative efficiency of markets, based on the price mechanism, which is the focus of neoclassical economic theory, can only deal with relative and not absolute scarcity. Since there is no substitute for low entropy matter/energy, to raise the *relative* prices of *all* of these resources would merely increase the absolute price level and cause inflation. Since Meadows et al. (1972) it became evident that in terms of sustainability, absolute scarcity of sinks is going to be even more problematic for future generations than that of natural resources. It will possibly be much easier for future generations to find a substitute for petroleum than to deal with climate change for example. Environmental Economics intends to counter pressures on the environment, which they regard as negative externalities, by internalising them via Pigou Taxes. This strategy again ignores the fact that most services provided by nature are scarce in an absolute way.

The so-called *weak* interpretation of sustainability is also based on factor substitutability. Human-made capital is assumed to be a perfect substitute for natural capital. Thus the loss or degradation of the stock of natural capital (resources and sinks) to future generations is being compensated by what is being created by humans (structures erected, technologies developed, knowledge gathered, etc.). The fact that virtually all human produced artefacts are 'perishable' (Ricardo 1817), i.e. they depreciate, is completely ignored. Most of them will probably have to be replaced entirely within 100 years time (Viktor 1991) (the same could be argued for technology and knowledge).

Natural capital and man-made capital are indeed supplements and not substitutes. This has often been illustrated on the example of the fishing industry. Historically, in an 'empty-world-economy' (see below), the scarce factor were the fishing boats (manmade capital). This role has been changed over the last decades. Now that we live in a 'full-world-economy' the scarce factor is fish (natural capital). New fishing boats equipped with high-tech instruments are in total not increasing the amount of fish caught, instead the opposite is true. Meanwhile over-fishing has lead to a decrease in the world stock of fish, which has dramatically reduced their reproductive capacity. Hence the fishing industry has clearly exceeded the limits of the newly scarce factor (Costanza, Norgaard et al. 1997).

Secondly, the mechanical value concept has a strong impact on the treatment of *time* in neoclassical economic theory. It is argued hat often even its very existence is denied. In those cases, where time *is* taken into account, it is treated in a mechanical way. There is no such thing as uncertainty; everything is known either with absolute certainty or in the form of some probability distribution (Georgescu-Roegen 1971 ch. 5-8; Edmonds and Reilly 1985; Perrings 1987). Furthermore the interaction between the economy and the environment is assumed to proceed in infinitesimal, qualitatively identical and *reversible* steps without the consideration of possible thresholds or points of no return (Söllner 1997). Reversibility therefore leaves humanity free to cut down forests, because they could be replanted; contaminate its freshwater supply, because it could be de-polluted; exploit species to extinction, because they could be re-introduced from stocks in zoos and botanical gardens or be reproduced in genetic engineering laboratories, etc.; In reality, "of course, all real economic (and other) processes are *irreversible*."(Söllner 1997 p. 181, own emphasis)

Finally technological optimism seems to act as a reinforcing and 'gap-filling' mechanism in neoclassical economic theory. It facilitates both, the assumption of factor substitutability (i.e. the rejection of absolute scarcity) as well as the assumption of reversibility. Human technological progress appears to be the panacea for mainstream economists. This optimism is by no means substantiated (Aage 1984) as the laws of thermodynamics will always impose limits. Of course physical laws have been found untrue in the past, but according to most physics, among those Albert Einstein, the laws of thermodynamics are the least likely ever to be overthrown (Daly 1992a).

1.3.1 Many problems one Solution

Neoclassical economics does not demand economic growth as such, but it provides the theoretical preconditions for it and sees it as "axiomatic necessity" (Georgescu-Roegen 1977). Orthodox economists are convinced that only economic growth can solve the 'classical problems' of society, formulated by Smith (poverty), Malthus (overpopulation), Marx (distribution) and Keynes (involuntary unemployment). Not only that, it is also offered as a (or the only) remedy for pollution problems, debt repayments, balance of payment deficits, depletion of natural resources, crime, etc. Most of theses claims are backed up by more or less plausible theories, most of which are hardly supported by empirical studies. Only poverty and environmental pollution shall be considered more closely her.

Firstly economic growth is portrayed as the "high tide that lifts all the Boats" (Daly 2001, p. 15). Although it does not increase everyone's relative income, it is supposed to do so with absolute income. If the *cake* is made larger, then everyone can (could) get a larger piece. This is the dominant philosophy with most governments and international organisations. In reality growth has resulted in a widening of the gap between the lowest and the highest incomes (Daly 2001). The IMF recently had to admit that despite growth in the West and in some developing countries; one fifth of the world's population has regressed (Palast 2001). The metaphor itself seems inappropriate for this argument, because as a matter of fact high tide in one part of the world causes low tide in another.

Secondly, it is alleged that societies experiencing economic growth will eventually begin to value their nature as a "luxury good" and start to protect it and repair the damage already done (e.g.: World Bank 1992). Selden and Song (1994) hypothesised that the environment-income relationship might be similar to that brought forward by Nobel laureate Simon Kuznets between income inequality and economic development. Seldon and Song (1994) argued that economic growth initially results in more pollution, which is eventually reversed, producing an inverted U-shaped curve, the so-called Environmental Kuznets Curve (EKC). While this hypothesis enjoys empirical support for some pollutants (Cavlovic, Baker et al. 2000), it does not hold true for example for carbon dioxide (Holtz-Eakin and Selden 1995) and several other important air pollutants (Harbaugh W., Levinson et al. 2000).

Moreover the EKC hypothesis is characterised by a variety of fundamental conceptual flaws, which have been described in detail by Tisdell (2001). Many of these flaws originate from the mechanical analogy discussed above. Thus it is assumed that pollution is *non-cumulative* and its effects are reversible. In reality it is a known fact that some pollutants are cumulative or could be regarded as such because of the long time they need to be broken up by the ecosystem (e.g.: CO_2 and CFCs). Moreover not all damage to the environment is reversible, such as the loss of biodiversity. Thresholds might be crossed after which ecosystems could collapse and require hundreds of years to recover.

Related to the EKC is the “dematerialisation hypothesis” or “de-coupling”. It is based on the argument that economies become more service and knowledge oriented as they grow and therefore use fewer natural resources. De-coupling is either achieved in an absolute sense or relative to GDP (weak dematerialisation). If its weak definition is adopted then the latter would suffice for achieving sustainability. Material and Energy Flow Accounting, which has celebrated great advances in recent years, continues to provide strong empirical evidence against dematerialisation (Haberl, Fischer-Kowalski et al. 2004). Although there are some economies that experience weak dematerialisation only, e.g.: Austria (Krausmann, Haberl et al. 2004), there are numerous examples in particular from southern countries where not even weak dematerialisation can be witnessed e.g.: Spain (Canellas, Citalic González et al. in press), Greece (Eurostat 2002) and Chile (Giljum 2004). It is further alleged that those industrialised countries, which do achieve weak or strong dematerialisation, do so by shifting “environmental weight” to southern, less developed counties. This hypothesis is know as “environmental load displacement” (Giljum 2004; Canellas, Citalic González et al. in press)

1.4 Uneconomic growth

In microeconomic theory the optimal scale of a microeconomic activity (production of a company or consumption of a household) is determined at the point where marginal costs equal marginal benefit. Indeed, variations of the solution of this problem dominate microeconomic theory. The law of decreasing marginal benefit indicates that after the point of optimal scale further growth becomes uneconomic, because costs are higher then benefit. A similar concept is not known in macroeconomic theory. According to Daly (2001), the reason for this is that microeconomics solely considers single parts – the growth of each part is limited by opportunity costs, which the rest of the system has to bear. Macroeconomics on the other hand only considers entirety and growth of the entirety does not cause opportunity costs, because there is no such thing as the ‘rest’ of entirety, which would have to bear such costs (Daly 2001).

In the absence of opportunity costs, there is no optimal scale for human economic activity and thus no limits to economic growth. As this growth has generated the advances of our modern society, at least in the west, in the absence of a trade-off, bigger can only mean better. This worldview completely ignores the role of the environment as a provider of vital goods and services. As already mentioned above, the economy is portrayed as a closed system. True, the rise of Environmental Economics *did* bring about recognition of the value of these services (compare: Costanza, d'Arge et al. 1997). However the environment is seen as a subsystem of the economy (Figure 41), which has to be brought under the governance of market mechanisms. In other words negative externalities have to be internalised and an economic value (in terms of money) has to be attributed to nature's services (e.g.: via contingent evaluation, travel cost method or hedonic pricing). Details and criticisms of these approaches are discussed at length elsewhere (e.g.: Martínez-Alier and Roca 2000) and are beyond the scope of this paper.

Because of substitution possibilities and technological progress the environmental sub-sector does not impose limits to the extension of the economy as Figure 41 above clearly illustrates. Ecological Economics offers a more "Copernican" approach, as the human economy is *not* seen as entirety but as a subsystem of the ecosystem. Figure 42 below is central to the ecological economic paradigm and summarises this "world view": The economy is depicted as a subsystem of the larger ecosystem, which has limits and is closed. Only with regards to the solar flow of energy can it be seen as open, however the solar flow is limited and non-growing.

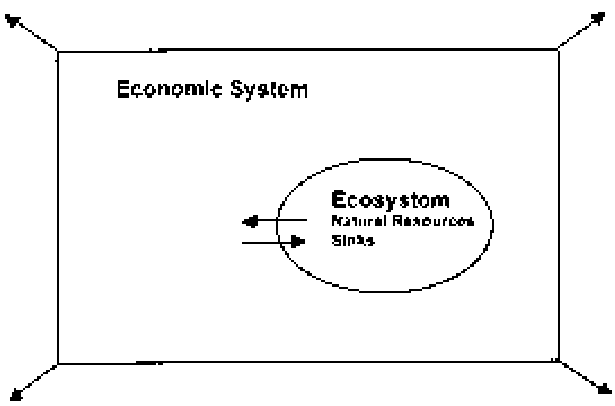

Figure 41: The ecosystem as a subsystem of the macro-economy (taken from: Daly 2001 p. 8)

Figure 42 shows two sources of human welfare: services from the economy and services from the ecosystem. A growing economy will transform natural capital in human capital, resulting in a larger flow of services from the economy and a smaller one from the ecosystem. Moreover growth of services from the economy reduces with an increasing economic system, because of the law of decreasing marginal utility. Assuming rational human beings, the most urgent needs are satisfied first. Since the economy claims ever more 'space' from the ecosystem, society has to give up ever more of its services. Assuming rational behaviour, the least important services will be given up first.

Hence there *are* opportunity costs involved in economic expansion, and there *is* an optimal scale for an economy, beyond which growth becomes *uneconomic*. The optimal scale could be defined as one for which total service, from the economy and the ecosystem, is maximised (this matter will be further discussed below). However the concept of microeconomic opportunity costs must be applied with caution, because of the interrelation of ecosystem services, i.e. giving a seemingly unimportant service up could affect other services in a chain reaction, which *are* important for humanity. Despite considerable advances in science, the interrelation and complexity of ecosystems or the climate on Earth are still far from being fully understood. In fact complexity in (natural) systems is now widely acknowledged and studied (Martinez-Alier, Munda et al. 1998). Attempting to determine an optimal scale with crude economic methods is therefore a daunting task and may not be appropriate.

Initially, when the economics discipline (including neoclassical economic theory) emerged, lost ecosystem services were arguably negligible, as economies were still small. As shown in Figure 42 the human society lived in an "empty world" (Costanza, Norgaard et al. 1997): empty of people and their artefacts but full of natural capital. Since the seventies evidence is mounting that humanity now lives in a "full world" i.e.: overpopulation (Ehrlich and Holdren 1971); approaching the limits of possible human appropriation of biomass (Vitousek, Ehrlich et al. 1986); climate change (IPCC 2002); ozone shield rupture (UNEP 2000); land degradation (Pimentel, Allen et al. 1987); biodiversity loss (Goodland 1991) and global water shortages (Shiva 2002).

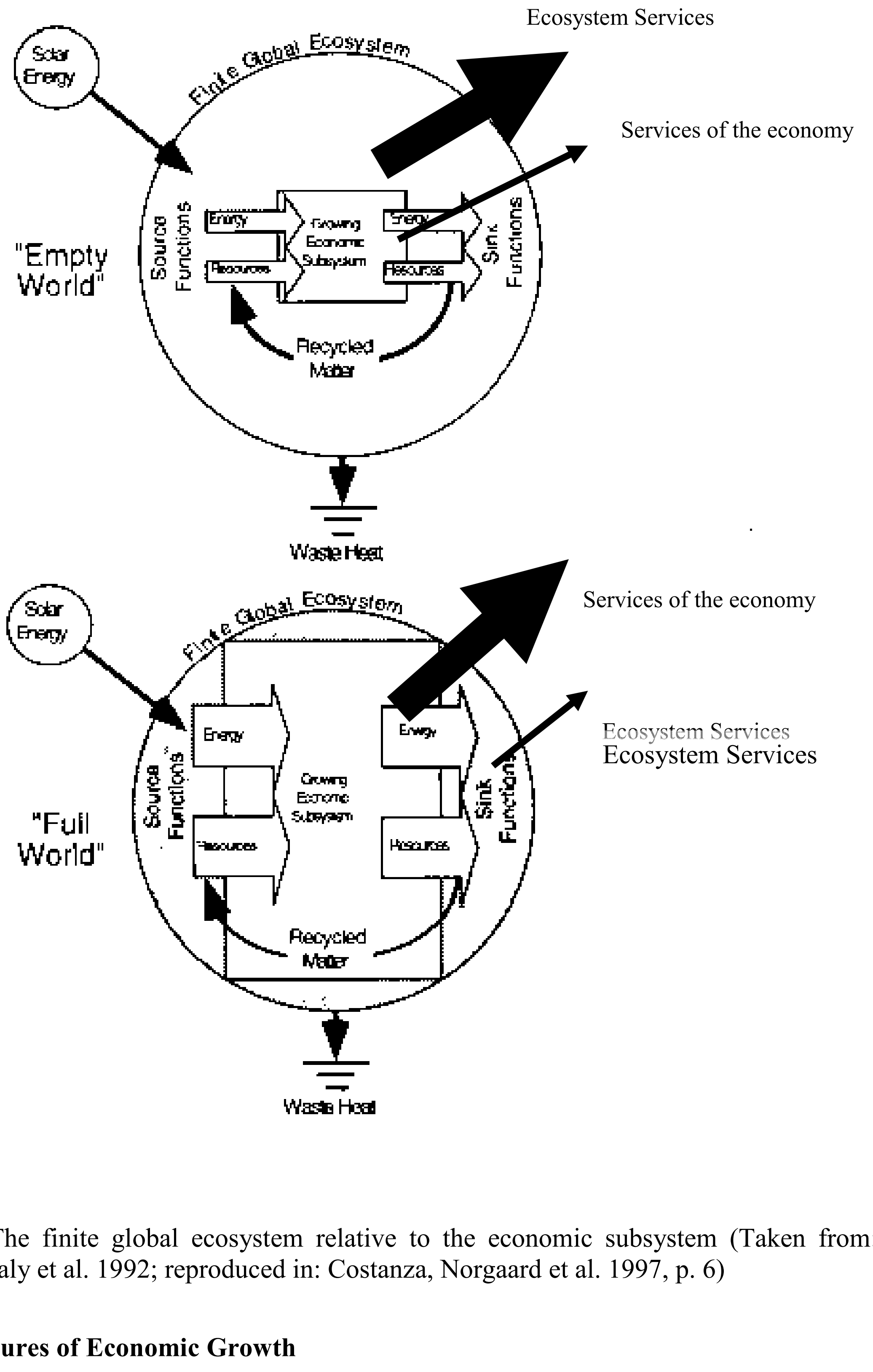

Figure 42: The finite global ecosystem relative to the economic subsystem (Taken from: Goodland, Daly et al. 1992; reproduced in: Costanza, Norgaard et al. 1997, p. 6)

1.4.1 Measures of Economic Growth

Usually when one talks of economic growth, one refers to an increase in the Gross National Product (GNP) or the Gross Domestic product (GDP). As an accounting tool GNP is perfectly legitimate, however its' use as an indicator of wealth is highly problematic. Daly (1992a) argues that GNP adds up three categories, which are very distinct and should be kept separate: throughput, additions to capital stock and services generated by this capital stock. Throughput is defined as the entropic depletion-pollution flow and it's the "*ultimate physical cost"* (Daly 1992a, p. 30) of economic activity. Hence the goal of maximising GNP also implies to some extent maximising costs! Service rendered by physical and human capital is benefit, or psychic income. Additions to capital stock represent a potential to render service in the future, but their costs (throughput) have been incurred already. Only by accounting for these magnitudes separately, would one be able to determine whether growth is actually still contributing to increasing economic welfare.

It should also be mentioned that GNP contains what has been defined as 'regrettable necessities' (Daly 1992a) or 'defensive expenditures'(Leipert 1989). This includes removal costs for environmental damages (e.g.: refuse collection) but also time and resources wasted because of modern lifestyles (e.g.: time lost when commuting, traffic jams, car accidents, etc.). These costs increase GNP instead of reducing it. Considering these facts it seems pretty counter intuitive to argue that GNP measures economic welfare. In fact hardly anybody explicitly does. The problem is however that *"everyone is using it in a way as if it did*." (Stockhammer, Hochreiter et al. 1997, p. 19)

Ever since GNP started to be used as a measure of welfare by proxy, it was met with scepticism ranging from Boulding in the 1950's to Daly in the 1970's. Numerous have thus been the attempts to extend / alter GNP (e.g.: 1988; El Serafy 1997) or to develop better national indicators altogether, such as the *Measured Economic Welfare* (MEW) (Nordhaus and Tobin 1972); the *Economic Aspects of Welfare* (EAW) (Zoltas 1981), the *Index of Sustainable Economic Wealth* (ISEW), the *Genuine Progress Indicator* (GPI) (Redefining Progress 1995), or more recently the *Sustainable Net Benefit Index* (SNBI) (Lawn and Sanders 1999; Lawn 2000). The evidence gathered from empirical applications of these indicators, in particular the ISEW, GPI and SNBI, suggest that in many industrial countries economic growth has actually become detrimental to human welfare (Lawn 2003).

Figure 43 below shows the revised ISEW for Austria with a widening gap between the two measurements (ISEW & GDP), particularly since the 1970ies. Daly and Cobb themselves however emphasised the necessity of a cautious use of these alternative economic indicators. They argue that any measure would abstract from many features of actual economic welfare.

One has to avoid the *fallacy of misplaced concreteness,* which is being described as "the fallacy involved whenever thinkers forget the degree of abstraction involved in thought and draw unwarranted conclusions about concrete actuality" (Daly and Cobb 1989, p 36). Ideally policy makers and analysts should have several indicators available; however this can also pose problems in those cases when individual indicators themselves point in opposite directions.

While the impact of the ISEW and other alternative measures has been minimal[114], the newly emerged field of Industrial Ecology provides new accounting tools, which could be used for a better interpretation of GNP. Material and Energy Flow accounting (MEFA) (Eurostat 2001), the Human Appropriation of Net Primary Production (Vitousek, Ehrlich et al. 1986; Haberl, Erb et al. 2001) and their combination with Input-Output Analysis seem promising candidates for becoming some kind of *sustainability indicators* (Haberl, Fischer-Kowalski et al. 2004). Hence they could serve not so much as measures of welfare, but to better interpret GNP. The economic growth in Chile for instance is often portrayed as the result of its role-model behaviour in terms of implementing neo-liberal development strategies. A study by Giljum (2004) however established a case to argue that Chile is fuelling its economic growth by overexploitation of its natural resources and indeed by impoverishing itself. The MEFA framework and Input-Output Analysis could become important tools for establishing the optimal scale in terms of energy and mass throughput of an economy and should therefore be central to the growth debate.

[114] In terms of the ISEW, Stockhammer et al. (1997) conclude "while ISEW seems qualified to kick GDP from the throne as leading indicator for economic policy, it is not ready to usurp that throne." (Stockhammer et al. 1997, p. 33)

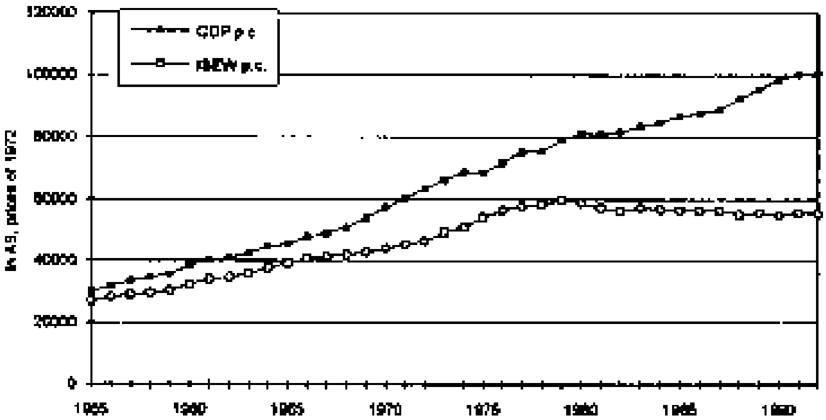

Figure 43: GDP and ISEW per capita for Austria from 1955 – 1994 (taken from: Stockhammer, Hochreiter et al. 1997, p. 30)

1.5 Socio-ethical and physical growth critique

The standard textbook definition of economics, according to Daly (1992a), states that economics is the study of the allocation of scarce means among competing ends. *"[T]he object of the allocation is the maximisation of the attainment of those ends.*" (Daly 1992a, p. 18) However, much confusion about economic growth, in Daly's (1992a) view, arises from economist's sole focus on the middle range of his 'ends-means spectrum'. This implies that only the allocation of *intermediate means* (artefacts, labour power) to achieve *intermediate ends* (food, comfort, education, etc.) are considered. Figure 44 illustrates Daly's (1992a) ends-means spectrum.

While the right hand side of the continuum shows the different levels on the spectrum including some examples, the left hand side indicates the discipline that is traditionally most concerned with each corresponding level. Each intermediate level in the continuum is an end with respect to lower categories and a means with respect to higher levels. *The ultimate end* is therefore achieved through the *intermediate ends* which in turn are made possible through the service of the *ultimate means*. Only at the two extremes there is the pure end and the pure means. The *Ultimate End* is such that it does not derive its value from being an instrument for the attainment of some other end; it is elementally good in itself. At the other extreme, the *ultimate means* are those means, which are used for serving human ends but unlike intermediate means cannot be created by humans and are therefore unable to become the end of any human activity.

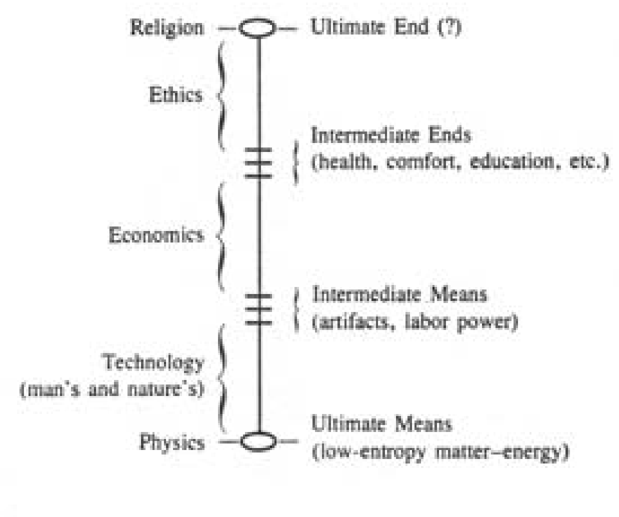

Figure 44: Daly's ends-means continuum (adapted from: Daly 1992a, p. 19)

By the mere concentration on the intermediate levels of the spectrum, economists traditionally did not include absolute limits in their consideration, because absolute limits can only be found in *ultimates*. This negligence of *ultimate ends* translates directly into a lack of attention to ethics. As mentioned before, due to the adoption of the mechanical value concept, ethical issues became a matter of personal taste and are therefore exogenous factors in economic models. *Ultimate means* and the absolute limits of their availability, situated on the other side of Daly's (1992a) spectrum, are equally ignored in mainstream economic theory. It is assumed technology can almost limitless transform ultimate physical means (low entropy matter-energy) into intermediate means.

The goal of never-ending economic growth can thus be defined "as the conversion of ever more ultimate means into ever more intermediate means (stocks of artefacts) for the purpose of satisfying ever more intermediate ends, whatever they may be."(Daly 1992a, p.23) Hence by looking only at the intermediate levels of the ends-means spectrum, economists came to the conclusion that although any given want can be satisfied, in the aggregate they are infinite and therefore can never be satisfied. It follows that if ends and means are unlimited, the process of growth may indeed continue forever.

1.5.1 Thermodynamics and Ultimate Means

Much to the contrary Nicolas Georgescu-Roegen (1971) argued that based on thermodynamics, unlimited economic growth is physically impossible. Ultimate means are in effect *low entropy*[115], which exists on earth in two different forms only: in terrestrial stock and in solar flow. Terrestrial stock can be divided into such resources, which are renewable in a human time scale and those only renewable in a geological time scale, known as *non-renewable*s. All of these sources of low entropy are absolutely limited. The non-renewables such as oil are limited in the total amount available on earth, while renewables are limited in rate of use, although they are practically unlimited in terms of the total amount eventually harvested over time (Daly 1992a). A similar argument can be made for solar flow which is practically unlimited[116] in total amount, but strictly limited in its rate and pattern of arrival to earth.

Although matter and energy cannot be created or destroyed, as the first law of thermodynamics states, it is being transformed during the economic production and consumption processes. This process always involves the transformation of low entropy states into high entropy states. Organised, structured and concentrated low entropy states of matter are for example converted into still higher structured commodities and then, through use, into dispersed, randomised, high-entropy states (waste). Energy is also transformed during the process of production and consumption of commodities. High-temperature energy for example, with a potential to do work becomes low-temperature energy whose ability to do work is lost as soon as the temperature equalises with its surrounding environment.

The most abundant source of low entropy on the planet is solar flow. All the worlds fossil fuels burned together would only provide a few days equivalent of sunlight energy (Daly 1992a). The rational thing for mankind would therefore be to use most of the non-renewable resources for the construction of facilities to better capture the energy of the sun. What has happened instead, during the last 200 years, is that the human economy has become dependent on the scarcest available forms of low entropy – non-renewable minerals. Technological optimists often argue that modern technology is freeing mankind from the dependence on resources (Barnett and Morse 1963; cited in: Daly 1992a). In Fact rather the

[115] Entropy is, technically speaking an extensive state variable (Baumgärtner 2003), which can be defined for any material substance or any system (Ayres 1998). An extensive state variable is a variable that "*is proportional to the size of the system and at any time only depends on the state of the system*" (Baumgärtner 2003 p. 1) Mass or volume are examples, whereas temperature or pressure would be examples for *intensive* variables. The second law of thermodynamics provides that entropy increases with every physical action or transformation occurring in an *isolated* system, i.e. a system that does not exchange matter or energy with other systems. Within such a system or in fact in the entire universe entropy can never decrease, which is why it has also been called 'time's arrow' (Ayres 1998). An internal systems equilibrium is reached, when entropy is maximised (Ayres 1998).

[116] It is generally assumed, that nuclear fusion on the sun will continue for another 4 -5 billion years. (http://en.wikipedia.org/wiki/Sun)

opposite is true. Technology, the *deus ex machina* of neoclassical economics, can only contribute to a more efficient use of the entropic flow, but will not be able to reverse the direction of the flow.

The reason why this heavy dependence on terrestrial non-renewables creates the illusion of more independence is because man can choose the rate at which he makes use of it. Solar flow on the other hand is limited and subject to seasonal and diurnal variations. Rapid economic growth is therefore easier to achieve, at least for limited time period, than with solar flow or renewable resources. The result is the depletion of geological capital and the overloading of ecosystems with newly produced materials for which no natural cycles exist (Daly 1992a). According to Daly's ends-means spectrum (Daly 1992a) low entropy is the 'real cost'; the ultimate opportunity cost involved in satisfying ends. Low entropy must be evaluated according to the worth of the best alternative sacrificed, since it can only be spent for one purpose (Daly 1992a).

1.5.2 Ultimate ends and sustainability

Ultimate ends are more difficult to define, than ultimate means. As a minimum, avoiding any religious issues, the ultimate end could be seen as the "survival and continuation of the evolving life process..." (Daly 1992a, p. 27). This is merely a crude definition of sustainability. Söllner (1997), in his search for ways to integrate thermodynamics (ultimate means) into economic theory concludes that this must be based on an explicit value decision (ultimate end). Sustainability is such a decision. It can only be justified on ethical grounds and can therefore not be left to the market. This decision must be followed by specific environmental policies [(Ayres (1991, 1994); Binswanger (1993) Daly (1991); Georgescu-Roegen (1979); Hampicke (1992); Hyman (1980); Slesser (1993); all cited in: Söllner 1997)]. Such policies would have to include *absolute limits* for the containment of the economy if it is to be sustainable (Daly 1991; Daly 1992b; cited in: Söllner 1997).

The growth paradigm rests on the two doctrines of relative scarcity of means as discussed above and the insatiability of wants to satisfy ends. Most of these ends can however not be served by aggregate growth (Daly 1992a). On the contrary, production and consumption and its side effects seem to get increasingly in the way. The satisfaction of some needs such as the need for leisure, contemplation, silence and conversation, become more difficult because of the production-consumption drive. There are already some social movements in place, which promote the enjoyments of a simple lifestyle. One group calls itself 'voluntary simplifiers'. They voluntarily reduce their consumption levels in order to live a materially simplified lifestyle and are part of a larger anti-consumption movement, which is constantly growing in number (Zavestoski 2002)[117].

Moreover it is incorrect that *all* wants are insatiable. John Maynard Keynes ((1963) 1997) distinguishes absolute and relative wants, only the latter of which he regards as unlimited. In affluent societies consumers derive most satisfaction from having something someone else does not have and not so much from the good itself. Relative wants are only felt when their satisfaction serves to distinguish oneself from others and makes one feel superior (Keynes (1963) 1997). Or as John Ruskin (1986; cited in: Daly 1992a, p. 27) wrote: "*the art of making yourself rich, in the ordinary mercantile economist's sense, is therefore equally and necessarily the art of keeping your neighbour poor*". Since everyone cannot be relatively better off then everyone else, relative wants may indeed be insatiable. Normatively it could be argued that the pursuit of relative wants, while many still struggle to satisfy their absolute wants (food, shelter, clothes, etc.) is inappropriate. Moreover it has to be questioned whether an economic model that requires people to be unsatisfied is indeed beneficial to humanity. The alternative to an economy based on the axiomatic necessity of growth is the steady state economy.

1.6 The history of the stationary state (steady state)

For most of man's history economic growth and the problems associated with it were not an issue. As illustrated above, humanity lived in an *empty world* until some 50 years after the onset of the industrial revolution in the late 18th and early 19th century. Before the industrial revolution the human economy could be described as *organic* i.e. not only foodstuffs, but most materials used for production could be traced back to organic (biotic) natural resources (Wirgley 1987; cited in: Luks 2001). Over about the last 200 years this has changed to the *mineral* economy we live in today. The most important impact of this change is of course environmental degradation.

Dennis Meadows (Meadows 1977; cited in: Luks 2001) argued that this was the point in time when humanity gave up sustainability and before that man basically lived in steady-state

[117] Nevertheless, despite these growing movements, most people still follow unsustainable consumption patterns and the overall consumption level is on the rise (Niemi 2006).

societies. This argument, if un-quantified, is clearly false. Human history is full of examples where societies have surpassed local carrying capacity by overexploitation of *renewable* resources. There is also evidence that even hunter-gatherers, despite only consuming less than 0.01% of the net primary production (NPP) of their habitat (Boyden 1992; cited in: Haberl, Fischer-Kowalski et al. 2004), contributed significant to local species extinction of their preferred prey (Sieferle 1997; cited in: Haberl, Fischer-Kowalski et al. 2004). Similarly agricultural societies such as the Ancient Mesopotamians gradually degraded their soils by irrigation techniques. Peasants had to first give up wheat production in favour of more salt resilient barley and finally had to abandon cultivation all together (Haberl, Fischer-Kowalski et al. 2004). This however only means that human history does not hold readily available sustainable lifestyle models. It does not mean that there cannot be a steady state alternative to economic growth.

1.6.1 The classical economists

All classical economists share the concept of a stationary state caused by population growth and decreasing revenues. They use the stationary state mainly as an ontological final point of economic development and only some also as an analytical fiction (compare Ricardo's famous chapter on machine capital).[118] The *ontological stationary state* has been defined as referring to economic reality, even if this reality is only expected to become relevant in a distant future. The stationary state is used in "the notion of an economy whose end-point of development is one in which capital accumulation has ceased because the profit-rate has fallen so low that there is no further incentive to accumulate capital" (Brandis 1989; cited in: Luks 2001).

The *analytical stationary state* on the other hand is an assumption that serves for analytical purposes only (Luks 2001). Marshall (1961 [1890]; cited in: Luks 2001) for example described the steady state merely as a "helpful auxiliary hypothesis". Because of its simplicity, the theory of a stationary state is used as a first step for the analysis of a more complex developing economy. The actual attainment of such a state is however regarded as "horribly unrealistic" (Meade 1965, p. 25; quoted in: Luks 2001, p. 29). Further it can be distinguished between the '*positive*' and the '*normative stationarity*' (Luks 2001): In the

[118] This statement is of course debatable: Kolb (1972) for example insists that Malthus and Ricardo used the stationary state only as "an analytical device rather than a view of reality because in terms of the time horizons which Ricardo and Malthus felt were operationally meaningful the stationary state was not considered to have substance at the level of reality" (Kolb 1972, p. 26; quoted in: Luks, 2001, p. 141)

former case stationarity is or will be attained by an economy without interference. The latter case refers to the perception of various authors such as John Stuart Mill, mentioned above, and nowadays Herman Daly, who believe in the desirability of a stationary state (e.g.: for ecological or social reasons).

It is assumed (Robbins 1930; cited in: Luks 2001) that the expression of a stationary state was first mentioned by Adam Smith (1723–1790), in "*The Wealth of Nations*" (Smith 1776). Although he certainly laid the foundations of the future growth paradigm, he did not believe that growth would be possible indefinitely. This was a worrying thought for Smith (1776), as growth for him was the source of wealth that would include all social classes. Only economic growth, he claimed, could prevent wages to fall to subsistence levels. In *Stationarity* wages and profits have to be low, which makes it a "dull" (Smith 1776, p. 99) state to be in. Thus for Smith (1776) the stationary state is ontological and equal to decreasing living standards and generally to poverty.

For Smith the "blessing" of economic growth could only continue until a country had attained its "full complement of riches" (Smith 1776, p. 99; quoted in: Luks 2001).This situation arises as soon as the necessary capital is accumulated. The maximum possible level of wealth is in turn determined by the land and climate of the particular country. Growth in "The Wealth of Nations" (Smith 1776) is therefore a temporary normality, which can continue for a long time, but not forever. Although Smith regards the 'dullness' of a stationary state unavoidable at some point, his work is generally known to be optimistic, unlike the writings of Thomas R. Malthus (1766-1834).

To Malthus both unlimited growth and a stationary state were impossible. He did not share Smiths optimisms for progress as he was convinced that "*no possible form of society could prevent the almost constant action of misery upon a great part of mankind, if in a state of inequality, and upon all, if all were equal.*" (Malthus 1993 (1798); quoted in: Luks 2001) Malthus came to this conclusion through what he called *population principle*, which is the basis of today's concepts of *carrying capacity* (Seidl and Tisdell 1999). Three basic facts are the essentials of his theory: Firstly the fact that human population increases exponentially (1,2,4,16, etc.).[119] Secondly food is necessary for the existence of man and is sole limiting

[119] Interestingly Malthus deducted this exponential growth from the increase in population in North America, not observed elsewhere at the time and which was largely accounted for by immigration, a fact he ignored.

factor on human population growth. Finally he claimed that food production could only be increased linearly (1,2,3,4,5, etc.).

For Malthus (1993 (1798)) these three facts were the explanation of the scarcities and misery he observed in England at the time. In his view there were two checks which naturally limit population: On the one side there is the foresight of the difficulties identified with the rearing of a family, acting as *a preventive check.* On the other side, "*the actual distresses of some of the lower classes, by which they are disabled from giving the proper food and attention to their children, acts as a positive check to the natural increase of population*."(Luks 2001, p. 111) Positive checks increase mortality (e.g.: famines, pests, wars, etc.) while preventive checks reduce the birth rate (e.g.: abortion, birth control, prostitution, later founding of families, etc.) (Gilbert 1993; cited in: Luks 2001).

Hence for Malthus all checks resulted either in vice or misery, which mankind was doomed to live with eternally. In other words he predicted that the human society would continuously fail to stabilise at a stationary state. Instead it would constantly overshoot its carrying capacity only to be decimated again by the forces of nature. Given the fact that Malthus' work was based on false empirical observations[120] because of normative assertions and a mechanistic concept of nature and society (Seidl and Tisdell 1999), it was surprisingly influential[121]. Even today it continues to be important for various academic disciplines.

While Smith concentrated on the conditions of economic growth, with a main interest in the effects of the division of labour, David Ricardo (1772 - 1823) focused his work on the limits of growth and on the analysis of capital accumulation and its effects on distribution (Luks 2001). His theory of distribution is based on the scarcity of land and its non-homogeneity in quality. An increasing population forces agricultural production to expand into marginal lands with lower and lower quality. That in turn requires a growing effort of labour, which is the reason for the increase in the value of the products of the land. As a result revenues of food producers decrease, while food prices increase. Labourers will then need higher wages, because their expenses increase with food prices. The increase of prices and wages can however only continue until wages equal the total income of the farmer. Then accumulation

Nevertheless this does not impinge on the validity of the assumption of exponential growth (Seidl and Tisdell 1999).

[120] See footnote above.

[121] Darwin for example claimed that Malthus' work inspired him for his work on evolutionary theory (Barnet and Morse 1963; cited in: Luks 2001).

must come to an end; "(...) *for no capital can then yield any profit whatever, and no additional labour can be demanded, and consequently population will have reached its highest point*" (Ricardo 1817; quoted in: Luks 2001, p. 119).

This means that for Ricardo, not the accumulation of capital itself leads to a decrease of profits, as it was claimed by Smith, but the connection between profits and subsistence costs. He stresses however that long before this state of high food prices and low wages, the very low rate of profits would have eliminated the motive for capital accumulation. The reason being that *„(...) no one accumulates but with a view to make his accumulation productive, and it is only when so employed that it operates on profits*" (Ricardo 1817; quoted in: Luks 2001, p. 120). Without such a motive for capital accumulation, the stationary state is unavoidable (Ricardo 1817; cited in: Luks 2001). However everything in Ricardo's writings points towards the fact that he believed this stationary state would only matter in a distant future. He believed that foreign commerce could prolong the attainment of the stationary state for a long time or even indefinitely (Ricardo 1817; cited in: Luks 2001).

John Stuart Mill (1806 – 1873) is often regarded as the last important thinker in the classical tradition (Welch 1989; cited in: Luks 2001) and is known as a sharp critic of the (then) existing capitalism. He was not only economists, but also philosopher and political scientist. Mill advocated a separation of production and distribution and for him economic 'laws' only apply to the former and not to the latter. (Schumpeter 1965 [1954]; cited in: Luks 2001)

Just like Malthus, Mill was convinced that technological improvements would eventually be unable to keep up with population growth, which would result in decreasing living standards. He is therefore a proponent of birth control measures. (Mill 1965 [1848]; cited in: Luks 2001). Whilst classicals before him postulated that an increase in living standards would automatically result in an increase in birth numbers, Mill hoped that this could be avoided for instance via education and birth control. This hope is important to understand his optimism regarding a stationary state, because in his view only a constant population would eliminate the permanent pressure on wage levels.[122]

The limiting factor for economic growth according to Mill is land but similarly to Ricardo he thought that such limits would only become relevant in the distant future (Mill 1965 [1848];

[122] This is a deviation from the writings of Smith and Ricardo. (Luks 2001)

cited in: Luks 2001). The question of limits was of ultimate importance for Mill and he saw the neglect of these issues by his colleagues not just as an error, (...) *but (as) the most serious one, to be found in the whole field of political economy*" (Mill 1965 [1848], p. 173; quoted in: Luks 2001, p 130) Without a thorough understanding of these limits to production, set by finiteness of the land and therefore the natural environment, so Mill, it is pointless to think about economic problems (Mill 1965 [1848]; cited in: Luks 2001).

Once a country reaches the *minimum rate of profitability*, he believed, no further increase of capital can for the present take place and that country will attain stationarity (Mill 1888). The attainment of the minimum profit rate depends on various conditions such as the propensity to accumulate and the security of capital. Although generally varying and difficult to identify such a minimum always exists in Mill's view. Countries with high levels of living standards are much closer to this state than poorer countries, unless the former are endowed with large yet undeveloped reserves of fertile land (Mill 1965 [1848]; cited in: Luks 2001). The attainment of this stationary state is therefore a result of the large amount of capital, which would be accumulated during a period free of crises. The actual time of this attainment could however, just as it was suggested by Ricardo, be prolonged by technological progress and by international trade (Mill 1965 [1848]; cited in: Luks 2001).[123]

For Mill the attainment of the stationary state as a final point in economic development, could be much further prolonged than for other classical economists. Nevertheless he hoped that future generations "(...) *will be content to be stationary, long before necessity compels them to it*" (Mill 1965 [1848], p. 756; quoted in: Luks 2001 p. 138). He 'romantically' thought of it as a condition where mankind had satisfied its essential needs and where it could focus its attention on other issues; away from the hectic and tense life of perusing commercial and economic goals (Claeys 1987; cited in: Luks 2001), with a society characterised by:

[123] Taking Mills argument further one could make the assertion that in order for growth to continue after a certain point (i.e. when technological progress does not keep up with population growth), the economy of a country either needs acquisition of another country's resources via trade or destruction via crisis (war?). It follows that a country can not only export and import goods but also sustainability (Pearce, Turner et al. 1993; cited in: Luks 2001). Some regions are apparently already "*running an unaccounted ecological deficit – their populations are appropriating carrying capacity from elsewhere or from future generations*" (Rees and Wackernagel 1994; cited in: Luks 2001). Germany for example would have to be a few times larger than it is, in order to produce everything consumed by its population. In other words Germany 'occupies' land belonging to other counties (Schmidt-Bleek 1994; cited in: Luks 2001). This phenomenon is known as ecologically unequal exchange in trade (usually from North to South) and is discussed extensively elsewhere (e.g.: Hornborg 1998; Muradian and Martinez-Alier 2001;)

" (...) a well-paid and affluent body of labourers; no enormous fortunes, except what were earned and accumulated during a single lifetime; but a much larger body of persons than at present, not only exempt from coarser toils, but with sufficient leisure, both physical and mental, from mechanical details, to cultivate freely the graces of life, and afford examples of them to the classes less favourably circumstanced for their growth. This condition of society, so greatly preferably to the present, is not only perfectly compatible with the stationary state, but, it would seem, more naturally allied with that state than with any other" (Mill 1888, p. 454).

Economic progress, in what he calls our "progressive society", subject to a growing capital stock, population growth and technical progress ("improvements in production") is unsatisfactory for Mill (1888) and he questions the goals of such a progress: *"(T)o what ultimate point is society tending by its industrial progress? When the progress ceases, in what condition are we to expect that it will leave mankind?"* (Mill 1888, p. 453). The argument clearly changes here from an economic one to an ethical one, which is also evident in the following quote. Mill therein reminds us of the fact that the stationary state was acknowledged by nearly all economists at his time:
"It must always have been seen, more or less distinctly, by political economists, that the increase in wealth is not boundless: that at the end of what they term the progressive state lies the stationary state, that all progress in wealth is but a postponement of this, and that each step in advance is an approach to it...(...) This impossibility of ultimately avoiding the stationary state – this irresistible necessity that the stream of human industry should finally spread itself out into an apparently stagnant sea – must have been, to the political economists of the last two generations, an unpleasant and discouraging prospect" (Mill 1888, p. 452).

Mill does not share this pessimism regarding the stationary state but on the contrary sees it very positively and desirable:

"I cannot ...regard the stationary state of capital and wealth with the unaffected aversion so generally manifested towards it by political economists of the old school. I am inclined to believe that it would be, on the whole, a very considerable improvement on our present condition. I confess I am not charmed with the ideal of life held out by those who think that the normal state of human beings is that of struggling to get on; that the trampling, crushing, elbowing, and treading on each other's heels which form the existing type of social life, are

the most desirable lot of human kind, or anything but the disagreeable symptoms of one of the phases of industrial progress. (...) (T)he best state for human nature is that in which, while no one is poor, no one desires to be richer, nor has any reason to fear being thrust back, be the efforts of others to push themselves forward" (Mill 1888, p 453).

In what could be considered as a kind of cultural critique on growth, Mill states that instead of growth, distribution and population control should be the main goals:

"*I know not why it should be a matter of congratulation that persons who are already richer than any one needs to be, should have doubled their means of consuming things which give little or no pleasure except as representative of wealth. (...) It is only in the backward countries of the world that increased production is still an important object: in those most advanced, what is economically needed is a better distribution, of which one indispensable needs is a stricter restraint on population*" (Mill 1888, p. 454).

In answering one of the first point of criticism which is normally brought forward against the stationary state, he claims that such a condition is *perfectly compatible with technical progress* and argues that this progress would even be stimulated:

"*It is scarcely necessary to remark that a stationary condition of capital and population implies no stationary state of human improvement. (...) There would be as much scope as ever for all kinds of mental culture, and moral and social progress; as much room for improving the Art of Living, and much more likelihood of its being improved, when minds ceased to be engrossed by the art of getting on. Even the industrial arts might be as earnestly and as successfully cultivated, with this sole difference, that instead of serving no purpose but the increase of wealth, industrial improvements would produce their legitimate effect, that of abridging labour*" (Mill 1888, p. 454).

This 'romantic' optimism about the stationary state is often criticised as absolutely utopian (Levy 1987 [1981]; cited in: Luks 2001) and incompatible with modern capitalist democracies. It is argued that Mill's vision of a stationary state is the result of his 'naive' believe that capitalism was only a transitional phenomenon, which would, driven by its own in-built dynamic, soon transform itself. Similarly to Marx, Mill believed that a fundamental societal change would have to take place for the kind of new social order that he had in mind

(Levy 1987 [1981]; cited in: Luks 2001). Unlike Malthus and Smith, Mill believed in society's ability to change fundamentally, a fact which is considered his main interest (Bladen 1974; cited in: Luks 2001).

Mill was clearly attracted to socialist ideas (Levy 1987 [1981]; cited in: Luks 2001), however he dissociated himself from the socialist critique of competition. He argued that it is not the best incentive, but absolutely necessary for societal progress and that any artificial limits to competition are wrong (Mill 1888). As stated by Levy, Mill expected the stationary state to be accompanied by a new, post-capitalist political economy, dominated by producer co-operatives (Levy 1987 [1981]; cited in: Luks 2001)[124].

Although most classical economists acknowledged the prolonging effects of technological progress on the limits to growth (and therefore on the stationary state), they had no idea of the changes brought about by the approaching industrial revolution. Economists, during and after this revolution, changed their visions fundamentally. In Karl Marx's (1818-1883) work, which is by many seen as classical - but at least Ricardian (Schumpeter 1965 [1954]; cited in: Luks 2001), capital and labour already become the most important factors of production and land loses its importance. His concept of stationarity (simple reproduction) is already merely an analytical fiction, which will be the case in the works of most of his successors.

Marx's 'simple reproduction' (Marx 1988 [1867], p. 592; quoted in: Luks 2001, p. 143) describes a mere repetition of the production process on the same level, which basically assumes net investment to be zero. It describes a situation of equilibrium, which Marx believed to be unachievable for a capitalist society. (Schumpeter 1993 [1942]; cited in: Luks 2001) He does however have his own vision of the ontological stationary state, but only beyond capitalism in his idea of socialism. Marx believed, that under socialism *"(...) output and real wages would increase up to the point where the society would decide, through some unspecified mechanism, that enough is enough (...).*" (Rostow 1990, p. 144; quoted in: Luks 2001, p. 144) Similarly to Mill's and much later Keynes's version of the stationary state, Marx's system is brought into a steady state equilibrium by diminishing relative marginal utility and not diminishing returns.

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[124] The contemporary author Douglas Booth (1998) also promotes producer co-operatives, as a way to establish a stationary state. He sees growth as inbuilt dynamic of the capitalist system, which is why capitalism in its present form is not compatible with a stationary state.

The work of Joseph Schumpeter (1883-1950) although not classical should be mentioned at this point, as he is neither a Marxist (although he liked Marx's ideas), nor neoclassical, nor a Keynesianist and he strictly opposed the formation of a 'Schumpeter – school' (Luks 2001). A considerable amount of his work was dedicated to the stationary state, which he calls 'circulation'. In 'circulation' whatever is produces is consumed in the same period and there are no savings, no profits and no capital, so credits are not needed (Schumpeter 1952 [1911]; cited in: Luks 2001). The main difference to his description of a developing economy however, is that it might grow (growth of population and wealth) but does not develop. Development, in his view, can only take place if entrepreneurs, financed through loans by capitalists, *push through new combinations* (Schumpeter 1952 [1911]; cited in: Luks 2001). (e.g.: new products, new markets, new sources of energy, etc.).

To Schumpeter the entrepreneur is the key to economic development (Wienert 1990; cited in: Luks 2001).. If there are no more credits for her available, or if a sudden change in the environment result in a situation, where she can no longer fulfil her function, then that's *the end of capitalism* for Schumpeter (Luks 2001). Exactly that is what he predicts in his late work '*Capitalism, Socialism and Democracy'* (Schumpeter 1993 [1942]), when his analytical stationary state becomes ontological. Capitalism is to collapse because of its own success, as "the growth and prosperity will eventually cripple the entrepreneur and his desire to innovate" (Allen 1994; quoted in: Luks 2001). Without the 'creative destruction' that he causes, specialist big enterprises will take over and innovation and development will stagnate.

According to Schumpeter (1993 [1942]) this self-destruction process of capitalism will eventually pave the way for Socialism. "*The capitalist process brings objects and souls into shape for Socialism*" (Schumpeter 1993 [1942], p. 351; cited in: Luks 2001, p. 165). However does this also lead to a stationary state? Schumpeter believed that capitalism cannot be stationary, which implies that a non-capitalist economy *could* be stationary. But also other statements in Schumpeter's work point towards such an assumption (Luks 2001). Schumpeter's prediction for the future of capitalism is therefore similar to that of Marx – capitalism cannot survive over the long term (Schumpeter 1993 [1942]; cited in: Luks 2001).

John Maynard Keynes (1883-1943) also doesn't fit the neoclassical tradition of rejecting the ontological stationary state. Just like for Schumpeter, stationarity only started to interest him at a later stage of his life, especially in *Economic Possibilities for Our Grandchildren (Keynes*

1972a [1930]). Contrary to what is mostly believed he was not a growth-fetishist, but had his own view of a pleasant future in a stationary economy; based on his ideal of a socially and economically just society, which respects the freedom of the individual (Nolte and Schaaff 1994; cited in: Luks 2001). Keynes was convinced that within the next hundred years the '*economic problem*' would be solved (Keynes 1972b [1931]; cited in: Luks 2001). The economic problem is "(...) *the problem of want and poverty and the economic struggle between classes and nations* (...)" (Keynes 1972b [1931], p. xviii; quoted in: Luks 2001, p. 167) or more generally the problem of scarcity. Before such a state can be established however, Keynes predicts a "*general 'nervous breakdown'*"(Keynes 1972a [1930], p. 327; quoted in: Luks 2001, p. 169) because "*mankind will be deprived of its traditional purpose*" (Keynes 1972a [1930], p. 327; quoted in: Luks 2001, p. 168) of struggling to solve the economic problem.

The scenario of abundance in which he describes a stationary state compares to that of Marx; contains similar 'romantic' features as Mill's stationary state and reminds of Hermann Daly's socio-ethical critique of growth. According to Keynes accumulation of wealth will lose its importance (Keynes 1972a [1930]; cited in: Luks 2001); the love of possessing money as an end and not a means will be recognised as "*somewhat disgusting morbidity*" (Keynes 1972a [1930], p. 329; quoted in: Luks 2001, p. 169). Just like Schumpeter he thought however that the time was not ripe for such a development yet. Until then those criticised values have the important function of guiding us "*out of the tunnel of economic necessity into daylight*" (Keynes 1972a [1930], p. 331; quoted in: Luks 2001, p. 170). Moreover, according to Keynes (1972a [1930]; cited in: Luks 2001) four factors determine the time when the light at the end of the tunnel will become visible: control of population growth, avoidance of wars, the role of science and the rate of accumulation.

As far as the role of science is concerned it appears in some of Keynes' statements that he was very optimistic about technological progress, because he believed that the economic problem would be solved by capital accumulation and technical innovations. Furthermore he claimed that the "standard of life in progressive countries one hundred years hence will be between *four* and *eight times* as high as it is today" (Keynes 1972a [1930], p. 325f; quoted in: Luks 2001, p. 168), or even higher. Although this was only written in 1930 and living standards (defined as material wealth) in industrialised countries might already be four times or more as high today. In other words Keynes writings do leave scope to interpret him as a growth-optimist and technophile, until humanity attains all the riches that he promised.

1.6.2 Neoclassical Growth Theory

As already mentioned, the paradigm shift during the 'marginal revolution' in the 1870ies brought about a destruction of the classical system according Schumpeter (1970 [1908]). With Marshall the stationary state became an analytical tool only and the concept of an ontological stationary state was rejected (Luks 2001). It was argued that classical economists had underestimated the potentials of technological progress. Moreover Malthus' and Ricardo's predictions regarding population growth and the situation of landowners respectively were not confirmed in the century following their work. Hence it is argued that "(...) *the empirical facts that the modern theory of growth attempts to explain are quite different from those which the classical theory confronted*" (Stiglitz and Uzawa 1969, p. 3; quoted in: Luks 2001, p. 176).

As a result the population principle became irrelevant by the end of the 19th century because the marginal utility system could incorporate any hypothesis of birth and death rates, preferred by the author (Schumpeter 1965 [1954]; cited in: Luks 2001).[125] Similarly land as a factor of production became irrelevant[126], which can partly be attributed to the increasing industrial sector (Perman, Ma et al. 1996; cited in: Luks 2001) and the declining importance of agriculture relative to manufacturing (Stiglitz and Uzawa 1969; cited in: Luks 2001). Today neo-classical (growth) theory focuses on capital and labour as the only factors of production. Land, the essential factor for economic growth in classical economics was 'replaced' by technical progress to provide theoretical possibility of unlimited growth (Stiglitz and Uzawa 1969; cited in: Luks 2001).

Solow's (1956; 1957) and Swan's (1956) essays are considered as the beginning of the neo-classical growth theory. Swan (1956; cited in: Luks 2001) describes a *classical case* characterised by one limiting production factor: land. Under these circumstances capital must grow faster than labour increase, in order to sustain per capita output, when confronted with decreasing land revenues. Since capital grows faster than output, profit continually decreases. Given this situation the economy tends towards a „*classical*" stationary state (Swan 1956; cited in: Luks 2001). Hence the inclusion of "(...) (*t)echnological progress, very broadly*

[125] A seperate discipline, demography, was created, which however seems to be excluded from the sustainability discourse.
[126] The incorporation of land into the production factor capital is nowadays common practise.

defined to include improvements in the human factor, was necessary to allow for long-run growth in real wages and the standard of living." (Solow 1988, p. 313; quoted in: Luks 2001, p. 179)

With the assumption that this progress compensates the diminishing returns, the economy tends towards a 'stable growth equilibrium' and not towards a classical stationary state (Swan 1956; cited in: Luks 2001). This equilibrium, also known as "steady-state growth", refers "*to models in which population and capital are growing absolutely, but in which certain ratios between absolutely growing magnitudes remain constant*" (Daly 1993, p. 366). This was seen as closer to reality considering the rapid growth in western industrial economies during the fifties and sixties. With technological progress and the assumption of quasi limitless substitutability of the factors of production as discussed earlier unlimited growth became (theoretically) possible.

1.7 Herman E. Daly's Steady State Economy

Daly could be considered as the „growth critical" writer who provides the sustainability discourse with the most important food for thought (Luks 2001). He bridges the growth discussion of the 70's (e.g.: Meadows, Meadows et al. 1972), with the recent sustainability discussion. While the former postulated a reduction in economic growth, he argues solely for a reduction of the throughput of material and energy. Together with Georgescu-Roegen, whose pupil Daly was, and Boulding, he is often seen as one of the founding fathers of ecological economics. The steady state economy (SSE), for which Daly is regarded as a theoretical father, is regarded by many authors as being one of the central pillars of the slowly developing structure of ecological economics (Luks 2000). Some authors even claim identity of ecological and steady-state economics (Underwood and King 1989; cited in: Luks 2000), while others such as Daly[127] himself talk of the identity of the latter with sustainable development (Schröder 1995; cited in: Luks 2000). This does however not mean that the SSE concept goes unchallenged, much to the contrary it is criticised by many as naïve and utterly utopian (e.g.: Proops 1989; Luks 2001).

Daly's vision of a SSE was inspired by Malthus and Mill in particular but also by other classical economists. He sees himself as a representative of a classical tradition, which is why he stresses the use of the term 'steady-state' in a classical sense, referring to what Mill called

[127] Daly for example talks of "sustainable or steady-state economics".(Daly 1996, p. 149)

'stationary state'(Daly 1981). John Stuart Mill used the term 'stationary state' to describe an economy in which population and capital stock had ceased growing. The noun *state* literally means the standing or stability of something (from the Latin stare, to stand). The adjective stationary (and steady) amplifies this idea of standing as opposed to running; of constancy as opposed to increase or decrease (Daly 1981).

The use of the term *stationary state* became problematic when the neo-classical economists redefined it to refer to an economy in which tastes and technology were unchanging but in which population and capital stock could be growing. Daly therefore adopted the term '*steady state'* from the physical and biological sciences, as "the term means to physical scientists nearly what the term stationary state had meant to the classical economists before the neoclassicals redefined it" (Daly 1981, p. 366). Adding to the confusion over terminology is the already mentioned concept of '*steady-state growth'*, defined by neo-classical growth theorists such as Hahn and Matthews (Hahn and Matthews 1964; cited in: Luks 2001). It even became a central concept in neoclassical growth theory e.g.: Stiglitz and Uzawa (1969; cited in: Luks 2001)

1.7.1 The Pre-analytic Vision

The vision of Daly's steady state concept is based on two physical magnitudes: A *stock* of capital (people and artefacts) and the physical flow of *throughput* (matter and energy) (Daly 1992a). The two physical populations of people and artefacts are characterised as providing *service* on one hand and requiring maintenance and replacement on the other. The stock of artefacts is directly dependent on the number of people, since they are considered as 'extensions of the human body', as has been suggested by Lotka (1956; cited in: Daly 1992a).[128] These artefacts (houses, cars,...) serve human needs (accommodation, transportation,...) and so do human beings to others (doctors, carpenters,...) and themselves.

However the artefacts wear out and have to be repaired or replaced and people need food, get cold, etc. and eventually die. Therefore there is a continuous inflow via production and birth and a corresponding outflow via depreciation and death of these two populations. This maintenance and replacement of artefacts and human bodies requires the throughput of matter and energy. This throughput begins with depletion of nature's sources of useful low entropy

[128] Lotka (1956) postulated the view of capital as "exosomatic organs". For example clothes and houses extend our skin; stoves, cooking utensils, and sewers extend the digestive tract; libraries and computers extend the brain, and so on.

(natural resources) and ends with the pollution of nature's sinks with high-entropy waste (waste, pollution and waste heat) (Georgescu-Roegen 1976; cited in: Söllner 1997).

From this general vision Daly (1992a, p. 17) deducts his 'stock orientated' definition of a SSE, [129] which he describes as: " (...) *an economy with constant stocks of people and artefacts, maintained at some desired, sufficient levels by low rates of maintenance 'throughput', that is, by the lowest feasible flows of matter and energy from the first stage of production (depletion of low entropy materials from the environment) to the last stage of consumption (pollution of the environment with high entropy wastes and exotic materials)."* Daly (1992a) emphasises that the SSE is a physical concept. What is being held constant, therefore, is capital stock, in the broadest *physical* sense of the term. Certain non-physical magnitudes, such as culture, knowledge, goodness, ethical codes, etc. are *not* held constant. In other words a SSE is an economy that *does* develop, but does not grow physically. As it was discussed earlier GNP adds up throughput, additions to capital stock and services generated by this capital stock. It is therefore irrelevant to the definition above. A large part of it reflects throughput and therefore a cost, which is why a reduction of GNP in a SSE is possible and totally acceptable, if it is a result of reduced 'costs'.

While the theoretical background for *capital* in the SSE originates from Lotka (1956), as mentioned above, *income* goes back to Fischer (Fischer 1906; cited in: Daly and Cobb 1989) " (...) that a proper accounting of income must reflect only the flow of services of capital enjoyed in the subjective stream of consciousness by people, during the relevant time period."(Daly 1992a, p. 36) To give an example, the purchase of a piano this year is not part of this year's income, but an addition to capital. This year's income on the other hand is solely the service rendered throughout the year by producing music.

Intermediate transactions, which involve the exchange and transformation of physical goods will, according to Fisher, cancel out, leaving only Fisher's "*uncancelled fringe*" of *psychic income* enjoyed by the final consumer (Fischer 1906; cited in: Daly 1992a). By taking this fringe and deducting the psychic disservices incurred in labour, Fisher arrives at his net psychic income, which he saw as the final net benefit of economic activity. However he does

[129] At the beginning of the 1990ies, Daly has gone over from a 'stock-oriented' to a 'flow-oriented' definition of a steady state, which however does not vary in its economic objectives. Therein a Steady-State-Economy is described as an economy "*whose throughput remains constant at a level that neither depletes the environment beyond its regenerative capacity, nor pollutes it beyond its absorptive capacity*." (Daly 1992a; quoted in: Luks 2000, p. 46)

not include the ultimate real costs, against which the ultimate value of net psychic income should be balanced. Daly therefore supplements Fisher's income with the physical concept of real costs elaborated by Kenneth Boulding (1966) and Nicholas Georgescu-Roegen's (1971). These unavoidable costs are due to the fact that the stock of capital wears out and has to be replaced (Georgescu-Roegen's fourth law, see below). After these clarifications the three basic magnitudes of Daly's SSE, can be summarised as follows:

STOCK	"The total inventory of producers' goods, consumers' goods, and human bodies. It corresponds to Fisher's (1906; cited in: Daly 1992a) definition of capital and may be thought of as the set of all physical things capable of satisfying human wants and subject to ownership."(Daly 1992a, p. 35)
SERVICE	"The satisfaction experienced when wants are satisfied, or 'psychic income' in Fisher's (1906; cited in: Daly 1992a) sense. Service is yielded by the stock. The quantity and quality of the stock determine the intensity of service." (Daly 1992a, p. 35) There is no unit for measuring service, so it is debatable whether it can really be called a 'magnitude'. Nevertheless, everyone can and is experiencing service or satisfaction and recognise differing intensities of the experience. Although service is yielded over a period of time and thus appears to be a flow magnitude, it cannot be accumulated, but flows can. Therefore it is probably more accurate to think of service as a psychic flux (Georgescu-Roegen 1971; cited in: Daly 1992a). Service is the final benefit of economic activity
THROUGHPUT	"The entropic physical flow of matter-energy from nature's sources, through the human economy, and back to nature's sinks and it is necessary for the maintenance and renewal of the stocks"(Boulding 1966; Georgescu-Roegen 1971; Daly 1992a, p. 35) "The throughput flow does not yield services directly; it must be accumulated and fashioned into a stock of useful artefacts (capital)."(Daly 1992a, p. 36)

Table (47): Daly's definitions of stock, service and throughput (adapted from: Daly 1992a, p. 36)

Going back to the discussion of the optimal scale of an economy, this could now be defined as one for which total service, from the economy and the ecosystem, is maximised. According to Daly (1992a, p. 35) "[*T]his will occur, when the addition to service arising from a marginal addition to the stock is equal to the decrement to service arising from impaired ecosystem services that result from the incremental throughput required by the increment in stock*." For reasons already mentioned above it might not be appropriate to attempt to compute such an optimum. Instead Daly (1992a) advocates *satisficing* because "it is a better strategy than optimising; that is it is better to be safe than sorry. Minimising future regret is wiser than maximising present benefit."(Daly 1992a, p. 35) The following identity illustrates the interrelations between Daly's three magnitudes:

Daly's identity	service / throughput ≡	service / stock X	stock / throughput
ratio	(1)	(2)	(3)
efficiency measure	throughput service efficiency	stock-service efficiency	stock-maintenance efficiency
limits	--------------	possibly: human nervous system and time	2nd law of thermodynamics

Table (48): Service, Stock and Throughput and their interrelations
(adapted from: Daly 1992a, p. 36)

Capital stocks are at the centre of Daly's analysis, because they are the intermediate magnitudes – accumulated throughput, temporarily frozen in ordered structures. On one hand it provides services (ratio 2), on the other hand it needs throughput for maintenance (ratio 3). Stocks in ratio (2) and (3) cancel out just as they wear out in the real world. The ultimate benefit that remains is therefore service, not stocks and the ultimate cost of service is throughput, or better, the sacrificed ecosystem services provoked by the throughput. "Stock is neither a benefit nor a cost, but both benefits and costs are functions of the stock." (Daly 1992a, p. 37)

Each of the three dimensions requires a different treatment in Daly's (1992a) steady-state paradigm. Stocks should be *satisficing*, which means that a level should be chosen, which is sufficient for a good life and sustainable for a long future. Throughput on the other hand is to be *minimised*, subject to the maintenance of the constant stocks and service is to be *maximised*, subject to the constant stocks. As indicated in Table (48) above, ratio (1) embodies the final service efficiency of the throughput i.e. the final benefit over the final costs, ratio (2) represents the service efficiency of the stock and ratio (3) the stock-maintenance efficiency of the throughput. Economic development in terms of these ratios can thus be defined as increasing ratios (2) and (3) and thereby getting more service out of each unit of throughput. Economic growth on the other hand means increasing service by increasing the size of stocks, but with no increase (or even a decrease) of the efficiency ratios 2 and 3. Thus the steady-state economy would force an end to pure growth, by holding stocks constant and would not curtail, but stimulate development (Daly 1992a).

While ratio (3) is according to Daly (1992a) limited by the second law of thermodynamics, the limits for ratio (2) (service efficiency) are less clear. It could be argued that there are no limits to the amount of service derivable from a given stock. On the other hand, as was mentioned above, at a certain level, further stock could just get in the way of welfare. Moreover one could consider the limits to the human nervous system: For example the human eye does not recognise a further improvement in quality above a certain amount of pixels per inch of a computerised image. Time could also be mentioned as a limit in the sense that someone who owns a tennis racket and then buys golf clubs, he will have less time for his tennis, the more gadgets one owns the less time one has for each of them, thereby setting a limit to service derivable from them.

These considerations beg the question, of how much stock is enough? This question is inherent in the sustainability discourse as such. If the Brundtland sustainability definition (WCED 1987), is adopted a similar problem arises over the definition of *needs*. Often it is argued that there is no point in advocating an SSE unless we know what exactly the optimum level of stock is. According to Daly (1992a) this is a wrong inference for two reasons: Firstly stability and viability are more important than optimality. As the actual levels of population and artefact stocks are historically given, humanity should first learn how to become stable and then worry about the optimum. Secondly, as it has been mentioned at the beginning of this paper, evidence from various fields of research is mounting that ecosystem limits of human expansion have already been reached. According to some authors the optimum has already been overshot in the 1970ies (Meadows, Meadows et al. 1972; Daly 1992a).

1.7.2 The three institutions for Daly's SSE

Daly (1992a) insists on the absolute necessity of a steady state and he provides a seemingly sound and holistic concept to attain it. This includes also three concrete institutional recommendations. However Daly (1992a) points out that there might be other institutions that could be more appropriate. The three institutions are based on two widely excepted economic establishments, the price mechanism and private property, but Daly (1992a) extends them to areas, where they were not applied previously: control of aggregate births and control of the aggregate throughput. Given the definition of a SSE above there is a need for (1) an institution for stabilising population; (2) an institution for stabilising the stock of physical artefacts and keeping throughput below ecological limits; and (3) a distributionist institution limiting the degree of inequality in the distribution of constant stocks among the constant population.

Firstly, and this is arguably the most controversial suggestion, Daly (1992a) advocates transferable birth licenses, as put forward by Kenneth Boulding (1964). Boulding's plan combines macro-stability with micro-variability and suggests that every woman[130] should be issued with an amount of reproduction licenses that corresponds to replacement fertility (or less if a reduction in population numbers was needed). Hence, they would receive 2.1 licenses each. The licenses would be divisible by units of one-tenth, where ten such units give the legal right to one birth. Licenses are freely transferable by sale or gift which means that those who want more than just two children can either buy them on a competitive market or acquire them by gift. It shouldn't come as a surprise that this concept was received with scepticism and rejection, which should however not be elaborated upon here.

A second institution is to limit the degree of inequality and the size and the monopoly power of corporations. This is to be achieved via minimum and maximum limits on income and a maximum limit on wealth[131]. There is hardly any economic reasoning behind this proposal. Daly (1992a) merely states that the other institutions would not be accepted without this one, as private property and the whole market economy lose their *moral basis* and the case for extending the market to cover birth and depletion quotas would not be strong enough (Daly 1992a). In the absence of large concentrations of income and wealth, savings would be smaller because they would truly represent abstinence from consumption rather than surplus after remaining satiation (Daly 1992a). This would support stability because less expansionary pressures from large amounts of surplus would seek ever new ways to grow exponentially and thereby causing either physical growth, inflation, or both (Daly 1992a).

It is important to mention at this point that Daly's (1992a) SSE is not motivated by a leftwing ideology. It is based on conservative premises (private property, the free market, opposition to welfare bureaucracies and centralised control), but also follows the call for 'power to the people' since according to Daly (1992a, p. 55): "(...) it puts the source of power, namely property, in the hands of the many people rather than in the hands of the few capitalist

[130] To woman only, because the female is the limiting factor in reproduction and since maternity is more demonstrable than paternity. (Daly 1992)
[131] As wealth and income are largely interchangeable, a limit on both is needed (Daly 1992a). Moreover a concentration of wealth, according to Daly (1992a), becomes inconsistent with both a market economy and political democracy.

plutocrats and socialist bureaucrats." Daly (1992a) continuously emphasises that his approach is neither leftwing nor rightwing and calls on politicians and economists to stop thinking exclusively within these two directions.

On the one hand the proposition of such an institution might be intuitively very attractive but on the other hand it is clearly the component with the weakest theoretical foundation in Daly's (1992a) concept. A variety of problematic issues are not tackled, such as how to deal with intra-family accumulation i.e.: inheritance; the role of public limited companies and its stockholders and the possible cessation of entrepreneurial incentives.

As it has been argued earlier the market price can only take care of relative scarcity not absolute scarcity. Aggregate physical depletion quotas are therefore brought forward as the third SSE institution. Because of the law of conservation of matter and energy, a limit on aggregate depletion – i.e. an imposition of a control on the throughput flow – will also indirectly limit aggregate pollution. A limit on the throughput flow on the other hand also limits indirectly the size of the stocks maintained by that flow. Unlike the end-pipe approach adopted in the Kyoto Protocol (UNFCC 1997) or as advocated by Booth (1998), Daly (1992a, p. 56) insists that *"[e]ntropy is at its minimum at the input (depletion) end of the throughput pipeline and at its maximum at the output (pollution) end. Therefore, it is physically easier to monitor and control depletion than pollution - there are fewer mines, wells, and ports than there are smokestacks, garbage dumps, and drainpipes, not to mention such diffuse emission sources as runoff of insecticides and fertilisers from fields into rivers and lakes and auto exhausts*."

This is a direct critique of neoclassical environmental policy of 'internalisation of externalities' applied to Pigout type taxes and other policy tools based on the 'polluter pay's principle'. The problem with such taxes is that they do not necessarily limit aggregate throughput for the following reasons: While it is true that price plus tax determines demand in a given demand curve (assuming policy makers know their elasticity), these curves shift and are moreover subject to great errors in estimation even if stable (Daly 1992a). Such a shift of a resource-demand-curve could for example be induced by an increase in population, change in taste, and increase in income. If petrol for example was to be taxed more intensively this could have two effects both of which would not necessarily result in less resource use. People could use their cars less and change to say riding bikes or using (cheaper) public transport, but would then maybe spend the money they saved on other resource intensive goods – the so-called rebound effect (see e.g.: Hertwich 2005). And secondly, people could simply change the components of their budged - i.e. continuing to use the car as much as before but spending less money on other consumption or on savings.[132] Moreover the effects of a tax could be offset by a credit expansion by the banking sector, an increase in velocity of circulation of money, or deficit spending by the government for other purposes (Daly 1992a). Taxes are therefore not suitable for limiting aggregate throughput (Daly 1992a).

In fact pollution taxes could actually lead to an increase in throughput. Resource extraction industries could seek more effective technologies to increase depletion, in order to become competitive again by. Many developing countries are heavily dependent on exports of one particular natural resource (e.g.: Chile and Copper). If they receive increasing competition from the recycling industry, which ultimately profit from pollution taxes, they could be forced to extract more in order to avoid a decrease in income. Nevertheless pollution taxes are useful, but only for fine-tuning at the micro-level (e.g.: for regulating one particular industry), on the macro-level some form of quotas would be more effective in reducing aggregate throughput.

Daly describes the market for resources in his SSE as two tiered. The government would first of all exercise a monopoly in the auctioning of limited quota rights to many buyers. These resource buyers, after having bought quota rights, would then meet many resource sellers in a competitive resource market. The market resource price would tend to equal marginal costs and more efficient producers would earn differential rents. The pure scarcity rent resulting from the quotas, would be captured in the depletion quota auction market by the government monopoly (Daly 1992a). This windfall rent could be used to finance the minimum income component of the distributist institution, as discussed above. Such a type of redistribution mechanism is also made necessary by the fact that the poor would suffer most from an increase of prices of most goods because of the quotas.

The direct effect of such a policy would be that pollution would be reduced as aggregate throughput decreases as the first law of thermodynamics predicts (Ayres 1998). Indirectly probably all products would become more expensive, but mainly those using many of the limited resources. This would encourage switching to less resource intensive goods, recycling

[132] Fuel taxes in the UK (€ 766 per 1000 litres) for example are almost twice as high as in Germany (€ 440 per 1000 litres), which has the second highest fuel taxes in the European Union (Ökosoziales Forum Österreich 2003) Nevertheless the British are among the most intensive car users in Europe.

and the investment in resource saving technologies and methods to capture the *free energy* from the sun more effectively. The quotas could also be used to impose a maximum corporate size, by not allowing a single entity to own more then x percent of the quota rights for a given resource or more than y percent of the resource owned by the industry of which it is a member. X and y could then be set in order to allow for legitimate economies of scale.(Daly 1992a)

Quotas would at first be set at present levels of resource consumption, with the first task being to stabilise the system and stop an increase in resource use. Then it should be tried to reduce quotas to a more sustainable level in order to avoid excessive pollution and ecological costs for present and future generations. For renewable resources quotas should be priced considering some reasonable calculation of maximum sustainable yield. Quotas for non-renewables on the other hand would reflect purely ethical judgement in terms of how many resources should be left for future generations – a decision the market is unable to make because future generations cannot bid in present resource markets.

In summary Daly's (1992a) SEE concept uses the allocative efficiency of the market for (1) the allocation of the limited aggregate of resources among competing firms; (2) the reallocation of the birth licenses, after they have initially been distributed equally among all people and (3) distribution of the income within the maximum and minimum boundaries. The combination of all three institutions offers, according to Daly (1992a), a good reconciliation of efficiency and equity, while at the same time it provides the ecologically necessary macro-control of growth, with the least sacrifice in terms of micro-level freedom and variability. The market is allowed to move freely within the imposed ecological and ethical boundaries.

1.7.3 SSE Critique: Utopia and moral growth

To most people Daly's (1992a) SSE concept is simply utopian and he admits himself that in the short run it is probably not an option. However in the long run, if people voted for it because environmental degradation and the problem of overpopulation became more evident and if there was, the necessary *moral growth* then it could work (Daly 1992a). The fact that Daly (1992a) relies heavily on this "moral growth"[133] in society has lead some authors to

[133] Daly (1992a) names altogether four moral first principles upon which he built his Steady State concept: some concept of enoughness or material sufficiency; a sense of stewardship for all of creation and an extension of brotherhood to future generations and to subhuman life; humility – not everything that can be done, has to be done and holism i.e. recognising that the whole is greater than the sum of its parts:

suggest that he might have replaced the optimism for technical progress of the *neoclassical economists*, with his hope for moral growth, to cover the analytical shortcomings of his concept (Luks 2001). Daly's (1992a) responds is that science is still obsessed with positivism and statements about moral values or ethics in the social sciences are still taboo. *In scientists quest for mechanistic and sophisticated technological resolutions, " (...) appeals to moral solutions and to a correction of values are considered as an admission of intellectual defeat, as a retreat from the rules of the game – as cheating*" (Daly 1992a, p. 47). Moreover it could be argued that "*attitudes of 'more forever', 'aprés moi la deluge', and technical arrogance"* (Daly 1992a, p. 47) are also normative value statements.

A true weakness of the SSE concept is that the international perspective is truly underrepresented in Daly's (1992a) work. He (Daly 1992a, p. 71) points out that the scheme ('probably') must be designed to include imported resources. "*The same depletion quota right could be required for importation of resources, and thus the market would determine the proportions in which our standard of living is sustained by depletion of national and foreign goods. Imported final goods would now be cheaper relative to national goods, assuming foreigners do not limit their depletion. Our export goods would now be more expensive relative to the domestic goods of foreign countries. Our terms of trade would improve, but we would tend to a balance of payments deficit*." However he goes on to claim that the balance of payments can take care of itself by means of freely fluctuating exchange rates. Equilibrium would simply be restored by a rise in the price of foreign currencies relative to the *dollar*. "*If foreigners are willing to sell us goods priced below their true full costs of production, we should not complain*." (Daly 1992a, p. 71) This statement reveals Daly's "americo-centric" worldview and clearly excludes small countries from trying to attain a SSE. Furthermore, even for an economy as big as the US, a sudden drastic shift in demand to foreign products would surely cause major disruptions. Hence without the imposition of import taxes the introduction of Daly's (1992a) SSE concept would probably not be feasible. Is he therefore implicitly asking for a return to intensive trade barriers, or even autarky? Confronted with this question via email correspondence, Mr. Daly responded: "Regarding international relations I would not advocate autarky, but trade cannot be free, (...)"(Daly 2002) Nevertheless it is not clear from his response, what the solution would be for the SSE concept.

Apart from international trade, there is also immigration which would cause problems that are not addressed by Daly (1992a). Pressures caused by population increase through immigration would clash with the scheme of transferable birth licences and in general with the attempt to keep population constant. Hence borders would have to be closed to immigrants. On the one hand this seems a harsh and maybe unethical proposition. On the other hand it could be argued that it is better than to exploit immigrants as cheap labour. Also, if this policy would allow a country to become sustainable, resources would be freed up for the development of poorer countries. Clearly it is preferable to enable poorer countries to develop themselves instead of exploiting, not only their resources, but also their manpower.

There is also a problem during the transition towards a steady-state economy with regards to those who are already rich and powerful and to resource owners. Daly only addresses the latter as he points out that "(...) current resource owners would suffer a one-time capital loss when depletion limits are imposed and, in fairness should be compensated." However, if this compensation would push these individuals over the income/wealth maximum, it would be taxed away from them anyhow, making it equivalent to at least partial expropriation. It is naïve to assume that the rich and powerful would also be inspired by the generally hoped for "moral growth" and give up their position and possession without struggle. Although Daly suggests that the maximum income level could be quite generous at first, those who are expecting to have their fortunes taxed away, will do everything possible to prevent that from happening. Hence it seems that a 'Marxist-type revolution' would be a necessary precondition of a SSE.

Booth (1998) sees growth as an inbuilt dynamic of capitalism. Thereby he refers to Schumpeter's view that the creation of new industries based on new technologies is fundamental to macroeconomic growth. These new industries automatically create new environmental problems and moreover vested interests that oppose environmental regulations or the imposition of Daly's (1992a) institutions. He therefore argues that capitalism, at least in its present form cannot become sustainable and is not compatible with the steady-state paradigm (Booth 1998).

1.7.4 SSE critique: the second law of thermodynamics

Daly's pre-analytic vision, described earlier, is based on Georgescu-Roegen's (1971) interpretation of the entropy law. In particular on what he refers to as a 'fourth law of thermodynamics':"*[c]omplete recycling is impossible. (...) [M]aterial objects wear out in such a way that small particles (molecules) originally belonging to these objects are* *gradually dissipated beyond the possibility of being reassembled*."(Georgescu-Roegen 1971, p. 60) Without this law, so Daly (1992a), the economy could be a closed system, because a litre of petrol for example could be burnt over and over again and nothing would ever wear out. Although Georgescu's fourth law appears plausible, it is only based on rather intuitive arguments, which rest on a collection of practical examples. It cannot prove the theoretical impossibility of perfect recycling. In fact rather the opposite is true, it directly contradicts the first law[134], which clearly implies the possibility of complete recycling (Hall, Cleveland et al. 1986; Ayres and Kneese 1989; Binswanger 1992; Söllner 1997; Ayres 1998).

Ayres (1998, p. 198) argues that Georgescu-Roegen's (1971) 'fourth law' could only be true "(…) *if the recovered and purified materials were insufficient in principle to maintain the capital equipment required for the materials recovery operation.*" He adds however that this is certainly not true because materials are trapped in the gravitational field of the Earth (Ayres 1998). Even 100% recycling would theoretically become feasible if enough exergy[135] was available. "Given enough exergy any element can be recovered from any source where it exists, no matter how dilute or diffuse" (1998, p. 197). Thus gold or uranium for example could in principle be recovered from seawater. According to Ayres (1998), the main problem is environmental pollution until all the non-renewable resources are used up. The long-run dangers arising from human activity are not found in the finiteness of resource stocks, but the fragility of self organised natural cycles. In his critique of the misinterpretations of the entropy law, Ayres (1998) refers to some of Daly's central arguments…:

"*Service comes from two sources, the stock of artifacts and the natural ecosystem. The stock of artifacts requires throughput for its maintenance, which requires depletion and pollution of the ecosystem. In other words the structure (low entropy) of the economy is maintained by imposing a cost of disorder on the ecosystem. From the entropy law we know that the entropy increase of the ecosystem is greater that the entropy decrease of the economy. As the stock and its maintenance throughput grow, the increasing disorder exported to the ecosystem will at some point interfere with its ability to provide natural services*."(Daly 1992a, p. 34)

The central truth in this paragraph, is according to Ayres simply not true. The argument in the quote above would only be true if 'the ecosystem' is interpreted as the planet earth as

[134] Conservation of Matter and Engery
[135] available energy (Ayres 1998)

distinguished from the solar system, including the sun (Ayres 1998). Since it is however applied to 'the ecosystem' as in 'the biosphere' considered in isolation, the above quotation is a misinterpretation of the entropy law. Ayres then goes on to point towards a passage, where Daly (1992a, p. 277) argues that in recognition of a medium-run time frame (one generation or an average lifetime) " (...) *industrial growth is limited by the stock of terrestrial low entropy, rather than by the stock of solar low-entropy, which is superabundant but is itself irrelevant because solar energy is flow limited..."* For Ayres (1998), Daly (1992a) stumbles on a point of fact in this quote: Although solar radiation is flow-limited, "(...)*the flux of available low-entropy energy (exergy) from the sun is extremely large"* (Ayres 1998, p. 197). The biosphere apparently only utilises some 3% of the solar exergy arriving upon the earth's surface (Ayres 1998).

Ayres believes that very soon technology will be advanced enough to capture the solar flow more efficiently e.g.: photovoltaic cells and fuel cells powered by solar hydrogen. It would not affect the heat balance of the earth if for example deserts were to be covered by devices to capture solar energy and to transform it into hydrogen. The surface of the earth is also no particular limit because according to Ayres (1998), satellites could capture solar exergy and he concludes that "(..) in the long run, solar exergy is certainly available for human use in almost unlimited quantities." Ayres (1998) is possibly referring to the concept of an economy based on hydrogen (i.e.: hydrogen economy), which was later made popular by Jeremy Rifkin (2002).

Although Ayres claims that direct consumption of biomass by humans requires a tiny fraction of this amount, he also mentions a study by Vitousek et al. (1986). In this study it is estimated that around 40% of the earth's biosphere-production is already used by humans, when indirect uses are taken into account. At one point population would become too large even if energy were superabundant (unless settlements on spaceships are considered feasible). Ayres (1998, 199) admits that and even argues that "(...) a slightly disguised version of the dilemma posed by Malthus is upon us."

1.8 Conclusion

The aim of this paper was to establish a logical path from the already widely accepted paradigm of sustainability as it was defined by the Brundtland Commission (WCED 1987) over an extensive critique of the economic growth paradigm, to the necessity of the attainment of an economy that does *not* grow – a steady state economy. At the very end of this path, one possible concept for the attainment of such an economy by Herman Daly was provided and critically analysed. It has been shown, that most preconditions, for the growth paradigm, have its roots in the adoption of a mechanic value concept. Generous assumptions of substitutability of resources with other resources, as well as of natural capital and human made capital, coupled with seemingly limitless optimism in technological progress, have been identified as the main preconditions for the theoretical possibility of unlimited economic growth.

Furthermore, it has been demonstrated that economic growth is *not*, the panacea for most problems of human society. This is in particular so if growth as measured in GNP is indeed becoming *un*economi*c*, which seems to be the lesson from various empirical studies. Moreover according to Georgescu-Roegen's (1971) fourth law of thermodynamics, unlimited growth is physically impossible. Ayres (1998) on the other hand suggests that virtually unlimited growth becomes theoretically possible, as soon as the solar flow can be utilised more efficiently with future technological innovations. Although Ayres (1998) reasoning seems correct, it remains questionable, whether the theoretical possibility of 100% recycling has any practical relevance. In addition Ayres (1998) appears overly optimistic about the advances in energy technologies. The enthusiasm about a coming hydrogen economy, which he seems to refer to, is becoming increasingly controversial (e.g.: Luzzati and Franco 2005)

Daly (1992a) on the other side calls for prudent technological scepticism. Before such technologies are indeed available, humanity would be better served by trying to become stable. Natural resources are considerably undersold (El Serafy 1988; Daly 1992a) and the market mechanism cannot be relied upon to provide enough incentive for technological advances. By the time the hydrogen economy is ready to replace the carbon economy[136] it might be too late – the ecosystem damage could be too large for a recovery[137]. Daly's (1992a), depletion quotas, would automatically make natural resources more expensive, by charging a scarcity rent for the resource in the ground. This would not only guide technological research into the development of devices to better capture the solar flow, but also allow humanity to reduce its pollution impact gradually.

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[136] Which is not certain, if this will ever be the case.
[137] On a human time scale.

One could event take this argument further and ask whether it would be beneficial to humanity's current growth driven society, if it was to discover an unlimited source of energy. Daly (1992a) believes that such a discovery would only accelerate the process of environmental destruction. A population explosion coupled with rapidly expanding economic activity would cause the collapse of ecosystems and the breaking out of famines and wars (Daly 1992a).

Moreover it has been mentioned, that there is already strong evidence that humanity is approaching the ecosystem limits, most of which are directly related to total number of people on the planet. Vitousek et al.'s (1986) state that around 40% of the net primary product of terrestrial photosynthesis (NPP) is already appropriated by human activities. The Brundtland Commission (WCED 1987) concluded in 1987 that in order to guarantee US living standards for all of the world, this would require a multiplication of economic outputs world-wide by a factor of five to ten (Vitousek, Ehrlich et al. 1986) - a goal, which is simply impossible[138]. Climate change, ozone shield rupture, land degradation and biodiversity loss are further evidence for the impact of human economic activity and the approaching of ecological limits.

In a socio-ethical growth critique, it has further been demonstrated that unlimited economic growth, even if possible, may actually be undesirable. Alternative indicators to GNP show a decrease in welfare for about the last 40 years. Moreover the satisfaction of ultimate ends (whatever they may be) and the cultivation "*of the graces of life*" (Mill 1965 [1848]) appear to be endangered by the growth economy's need for a dissatisfied consumer. Servicing insatiable relative wants has become the *raison d'etre* of the western economic system. At the same time in other parts of the world, people are still struggling to satisfy their most basic needs.

It has been argued that without *moral growth* Daly's SSE concept would probably not be feasible. However, the adoption of the goal of sustainable development, which is clearly based on ethical values and normative concepts, might be the first sign of such growth. Nevertheless, issues of sufficiency, frugality and most of all life style changes are still underrepresented in the sustainability discourse. The same is true firstly for tackling

[138] Technological optimists would again argue that these limits could be overcome by the advances of molecular bio-chemistry (or other disciplines). However given the considerable efforts that are under way already to produce crops with higher yields, world grain stocks have been decreasing considerably over the last years (Brown 2004).

overpopulation and secondly for decreasing distribution inequality by freeing up resources in wealthy countries. Eventually this discourse have to address these issues and thus will be unable to ignore the concept of a steady state.

Maybe the classical economists were right, and the steady state will come upon humanity by itself. Maybe Keynes and Schumpeter were right in regarding the present economic system merely as a path to a better (stable) economic order. Mill (1988) and Daly (1992a) argued that the voluntary transition to what seems inevitable at one point, would avoid major disasters to humanity in the future and create satisfying living standards for everyone. Nevertheless, it remains questionable whether a steady state, even if people voted for it, could be made compatible with the capitalist system of today. Thus it is unclear whether the institutions proposed by Daly (1992a) or Booth (1998) could put the capitalist system within boundaries or if, as it was implicitly assumed by Mill, Marx, Schumpeter and Keynes, a steady-state economy would be equal to socialism. On the other hand, would it matter what the economic system it was, if moral growth became as strong as Daly hopes?

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Economic de-growth vs. steady-state economy

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ABSTRACT

In recent years the concept of economic de-growth (decroissance) based on the literature of Nicolas Georgescu-Roegen e.g. [1–3] has found a revival in France, Italy, Spain and other countries, in the popular as well as in the academic literature. Therein authors took on board Georgescu-Roegens' categorical rejection of a steady-state economy (SSE), as proposed by Herman Daly [4]. They argue that economic de-growth is the only viable alternative goal to the growing economy. This position is challenged in this article and it is concluded that the two concepts are in fact complements. Economic de-growth is not a goal in itself, but the rich North's path towards a globally equitable SSE. Moreover the de-growth literature can benefit from the strong economic historic roots of the SSE and from Daly's macroeconomic concepts, while in return being able to give lessons about bottom-up approaches. This would be particularly important for the population issue, where Daly proposes limited birth licences. Unfortunately statements on demography are inconsistent and underdeveloped in the de-growth literature. Further it is concluded that most criticisms of the SSE are due to a too narrow and technocratic interpretation of the concept. Instead the SSE should be defined as a quasi steady-state, resting in a dynamic equilibrium and as an "unattainable goal", which can and probably should be approximated.

1. Introduction

Economic de-growth in its somewhat smoother sounding French version 'la décroissance', first appeared in the scientific and political arena when Jacques Grinevald and Ivo Rens [5] translated some of the major works of Nicholas Georgescu-Roegen into French. The main idea behind the concept has recently been defined as: "An equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long-term" [6, p. 3]. Georgescu-Roegen, the author of *The entropy law and the economic process*, challenged, what he called the 'growth mania' [3] of mainstream economists [e.g. 2,7,8].[1] Best represented in the literature by Barnett and Morse [10], Solow [11,12], and the like, this paradigm still dominates the mainstream economic thought [e.g. 13,14] which proclaims that unlimited economic growth is both possible and desirable.[2]

Georgescu-Roegen's views coincided with and partly inspired those of other growth critics at the time: Hardin [16], Daly [4,17], Meadows et al., [18], etc. However with regard to the alternatives of the growing economy or "ecological salvation", Georgescu-Roegen [e.g. 3,19] fundamentally disagreed with the former. Just as Meadows et al. [18, Ch. 5] in their *Limits to Growth*, Herman Daly argued that attaining a sustainable state of the human economy was possible: namely the stationary or steady-state [4,17,20–22]. Strongly influenced by John Stuart Mill's [23] description of a stationary state and based on the thermodynamic world view of Georgescu-Roegen (who was his mentor [24]), Daly developed the first macroeconomic concept of such a desirable zero-growth economy. This proposition was met with fierce rejection from Georgescu-Roegen, who insisted that only a *declining* state was both feasible and desirable [3,19,25]. The de-growth movement in France, Italy and Spain,[3] to judge from its literature [26–30] is strongly influenced by this position of Georgescu-Roegen.

In this article diverging viewpoints regarding the steady-state economy (SSE) are revisited and it is argued that the de-growth authors' categorical rejection of the concept of a steady-state – if

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[1] Georgescu-Roegen was however neither the only, nor the most famous growth critic. For an overview see for example J.C.J.M. van den Bergh and R.A. de Mooij [9].

[2] It is supposedly physically possible because of a dematerialising economy and the substitutability of non-renewable resources, both of which are the results of equally limitless technological progress. Moreover it is implicitly desirable, as it is seen as an "axiomatic necessity" [3, p. 266] to rid society of most social evils like unemployment, poverty, overpopulation and pollution [13–15].

[3] See the respective websites: www.décroissance.org; www.decrecita.it; http://decreixement.net;

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Economic De-growth vs. Steady-State Economy[139]

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Analysis

2.1 Abstract

In recent years the concept of economic de-growth (decroissance) based on the literature of Nicolas Georgescu-Roegen (e.g. 1971; 1976; 1977) has found a revival in France, Italy, Spain and other countries, in the popular as well as in the academic literature. Therein authors took on board Georgescu-Roegens' categorical rejection of a steady-state economy (SSE), as proposed by Herman Daly (1971). They argue that economic de-growth is the only viable alternative goal to the growing economy. This position is challenged in this article and it is concluded that the two concepts are in fact complements. Economic de-growth is not a goal in itself, but the rich North's path towards a globally equitable SSE. Moreover the de-growth literature can benefit from the strong economic historic roots of the SSE and from Daly's macroeconomic concepts, while in return being able to give lessons about bottom-up approaches. This would be particularly important for the population issue, where Daly proposes limited birth licences. Unfortunately statements on demography are inconsistent and underdeveloped in the de-growth literature. Further it is concluded that most criticisms of the SSE are due to a too narrow and technocratic interpretation of the concept. Instead the SSE should be defined as a quasi steady-state, resting in a dynamic equilibrium and as an "unattainable goal", which can and probably should be approximated.

2.2 Keywords

Steady-State Economy, Economic De-Growth, Population, Unattainable Goals, Georgescu-Roegen, Sustainability;

2.3 Introduction

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main idea behind the concept has recently been defined as: "An equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term" (Kallis and Schneider 2008, p.3). Georgescu-Roegen, the author of *The entropy law and the economic process*, challenged, what he called the 'growth mania' (Georgescu-Roegen 1977) of mainstream economists (Georgescu-Roegen 1966; e.g. 1971; 1972)[140]. Best represented in the literature by Barnett and Morse (1963), Solow (1974; 1988), and the like, this paradigm still dominates the mainstream economic thought (e.g. Spence 2008; World Bank 2008) which proclaims that unlimited economic growth is both possible and desirable.[141]

Georgescu-Roegen's views coincided with and partly inspired those of other growth critics at the time: Hardin (1968), Daly (1971; 1973), Meadows et al. (1972), etc. However with regard to the alternatives of the growing economy or "ecological salvation", Georgescu-Roegen (1975; e.g. 1977) fundamentally disagreed with the former. Just as Meadows et al. (Meadows, Meadows et al. 1972, Ch. 5) in their *Limits to Growth*, Herman Daly argued that attaining a sustainable state of the human economy was possible: namely the stationary or steady-state (Daly 1971; 1973; 1992; 2007; 2008). Strongly influenced by John Stuart Mill's (Mill 1866 [1848]) description of a stationary state and based on the thermodynamic world view of Georgescu-Roegen (who was his mentor (Maneschi and Zamagni 1997)), Daly developed the first macroeconomic concept of such a desirable zero-growth economy. This proposition was met with fierce rejection from Georgescu-Roegen, who insisted that only a *declining* state was both feasible and desirable (Georgescu-Roegen 1975; 1976; 1977). The de-growth movement in France, Italy and Spain[142], to judge from its literature (Ariès 2004; Latouche 2004; Bonaiuti 2006; Grinevald 2006; Latouche 2006) is strongly influenced by this position of Georgescu-Roegen.

In this article diverging viewpoints regarding the steady-state economy (SSE) are revisited and it is argued that the de-growth authors' categorical rejection of the concept of a steady-state – if properly defined – merits reconsideration. Section 2 highlights the strong historical

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[140] Georgescu-Roegen was however neither the only, nor the most famous growth critic. For an overview see for example J.C.J.M. van den Bergh and R.A. de Mooij (van den Bergh and de Mooij 1999).

[141] It is supposedly physically possible because of a dematerialising economy and the substitutability of non-renewable resources, both of which are the results of equally limitless technological progress. Moreover it is implicitly desirable, as it is seen as an "*axiomatic necessity*" (Georgescu-Roegen 1977, p. 266) to rid society of most social evils like unemployment, poverty, overpopulation and pollution (World Bank 1992; Spence 2008; World Bank 2008).

[142] See the respective websites: www.décroissance.org; www.decrecita.it; http://decreixement.net;

roots of stationarity in the classical and modern economic literature. Section 3 briefly describes Herman Daly's elaborated concept of a SSE. Section 4 is dedicated to population, an issue that is considered as being of utmost importance, but which appears to be mostly ignored or tabooed not only in the de-growth community, but also in the general sustainability discourse. Section 5 confronts the two positions, shows weaknesses and provides criticism of both, and section 6 introduces 'unattainable goals' and 'moral growth'. Section 7 concludes.

2.4 History of the Steady-State Economy

The term 'stationary state' was first mentioned by Adam Smith (Smith 1852 [1776], p. 34). Like Smith most classical writers had their own distinct theories about this state. Daly (2007) believes that this may be due to the fact that they still had a strong concern to adapt the economy to physical realities, whereas thereafter most economists have been busy engaging in the opposite. However many classical economists feared stationarity as the ontologically inevitable endpoint of economic growth and development caused by population growth and decreasing returns (Luks 2001). Smith for example was convinced that economic growth was the source of all wealth and therewith laid the foundations of the neoclassical 'economic growth paradigm' mentioned above. To him "...the stationary is (a) dull…" (Smith 1852 [1776], p. 34) state to be in and equal to poverty.

For Thomas Malthus (1807 [1798]; 1826 [1798]) it was indeed the inability of the human society to establish a stationary state that convinced him of its eternal condemnation to 'vice and misery'. This was the inevitable outcome of his '*population principle*': On the one hand humans are unable to control their exponential population growth. On the other hand food production is growing only linearly or indeed less than proportionately to the increased labour input because of decreasing returns, causing humanity's continuous overshooting of the carrying capacity[143] of its habitat. The result, according to Malthus, was 'misery' as the overshoot was to be cut back by positive checks, which increase the death rate (wars, famines and diseases) and preventive checks in the form of 'vices' (abortion, birth control, prostitution) [Ibid]. He somewhat softened his dire conclusion in the second edition of his essays, when he introduced 'moral restraint' (chastity and late marriage) as another possible preventive check (Gilbert 1993).

[143] Malthus did not use the concept of 'carrying capacity', which was developed much later, but his 'population principle' could be seen as the historical basis for this concept .

Known as the last important economist of the classical tradition (Welch 1989), John Stuart Mill did not share the pessimistic vision of Smith and Malthus regarding stationarity. In fact his Victorian prose on the subject provides the historical inspiration for Daly's 'normative' (i.e. desirable) steady-state. Mill in his own words thought of it as a situation with " (...) a well-paid and affluent body of labourers; no enormous fortunes, except what were earned and accumulated during a single lifetime; but a much larger body of persons than at present, not only exempt from coarser toils, but with sufficient leisure, both physical and mental, from mechanical details, to cultivate freely the graces of life…" (Mill 1866 [1848], p. 454). He was convinced that humans would "(...) be content to be stationary, long before necessity compels them to it" (1866 [1848], p. 454). He believed it would be a considerable improvement to the present state of social life, characterised by endless struggles to get on and by "(…) trampling, crushing, elbowing, and treading on each other's heels …" (1866 [1848], p. 453).

The experience of the enormous technological progress during and after the industrial revolution, fuelled by coal first and both coal and petroleum later[144], changed the economist's vision of the stationary state fundamentally. Classical worries about the limits imposed to the expansion of the human economy by decreasing returns in agriculture (Malthus 1807 [1798]; 1826 [1798]), the finiteness of arable land and decreasing returns (Ricardo 1821 [1817]) and the exhaustibility of non-renewable resources (Jevons 1866 [1865]), were brushed aside as dusty remainders of the early modern period. Economic growth now appeared unlimited and the stationary state mutated from an ontological reality to an analytical fiction (Luks 2001). This tendency was already visible in the works of Karl Marx, to whom land was not anymore as important as capital and labour in the production process. However in his very own concept of stationarity (simple reproduction) (Marx 1887, Ch. 23), though mostly analytical, Marx *does* seem to foresee a possible real state of equilibrium beyond capitalism. In socialism, he believed, diminishing relative marginal utility would induce society to decide "enough is enough" at some point (Luks 2001).

Joseph Schumpeter, a mentor of Georgescu-Roegen, was a notable exception to this tendency. He dedicated a considerable amount of his work to the stationary state, which he called 'circulation' (Kreislauf): an economy which consumes everything produced in each period i.e. without accumulation, credit, savings or profits (Schumpeter 1911; Schumpeter 1961 [1911]),

[144] Contrary to popular believe the use of coal has not declined since petroleum became more popular as a fuel. In fact, coal extraction increased seven times in the 20th century while population increased "only" four times.

similar to Marx's "simple reproduction" above (as compared to "expanded reproduction". This Schumpeter thought would be followed by the collapse of capitalism, to be replaced by socialism (Luks 2001). John Maynard Keynes also maintained his reservations with regard to the technophilia of his neoclassical peers and continued to write about an ontological (rather than an analytical) steady-state. He described a 'quasi stationary community'(Keynes 2002 [1936], Ch. 16), which would be characterised by a stable population, the absence of wars and several generations of full employment. The 'marginal efficiency of capital' would fall to zero, leading to a near zero interest rate and consequently the 'euthanasia of the rentier' (Keynes 2002 [1936], Ch. 24) – the inability to live of one's accumulated wealth.

2.5 Daly's SSE concept and institutions

Herman Daly's normative concept of an ontological steady state is inspired by this rich history above and by Georgescu-Roegen´s (1970) flow-fund model and thermodynamic growth critique. The former analytical model distinguishes between stocks, funds, flows and services. Stocks can be transformed into flows, serving as inputs for the economic process at any rate until they are depleted e.g. the transformation of fossil fuels (stock) into heat (flow). Flows are those factors of production that are transformed by the funds (capital, people and ricardian land) into either "useful" outputs (e.g. consumer goods) or unwanted outputs (e.g. waste). The funds, as described above, produce services just like stocks produce flows, however only at a limited rate. A labourer can only do so much work and so many hours a day, then she needs to rest. In a bakery, the baker (*labour-fund*) uses a furnace (*capital-fund*) to transform a *flow* of heat (coming from a *stock* e.g. coal or a *land-fund* e.g. wood) and flour into a *flow* of bread (consumer good) and ash (waste). Georgescu-Roegen insisted that humans should live of the services of renewable funds, and not of the flows from depletable stock (Georgescu-Roegen 1975).

As we shall see Daly's own analytical approach uses services and stocks in a different way, does not distinguish between flows and funds and introduces "throughput" instead. These changes allow him to describe his normative concept of an ontological steady-state as: "an economy with constant stocks of people and artefacts, maintained at some desired, sufficient levels by low rates of maintenance 'throughput', that is, by the lowest feasible flows of matter and energy from the first stage of production (depletion of low entropy materials from the environment) to the last stage of consumption (pollution of the environment with high entropy wastes and exotic materials)*."* Daly (1992, p. 16).

The ratios and efficiency measures given in Equation (135) constitute the core of this SSE concept. Therein the economy is described as a stock of people and artefacts, which require maintenance via throughput of a flow of physical matter and energy. Stocks provide service, and as shown in ratio 2 and 3, cancel each other out just as they wear out in the real world. Ratio 2 constitutes the stock-service-efficiency[145] and ratio 3 the stock-maintenance-efficiency[146]. Service is the ultimate benefit of economic activity and should be maximised while throughput is the ultimate cost of this service and should be minimised. De-growth 'prophet' Serge Latouche's eloquently popularized recommendations for socio-economic transformation, wrapped up in an ever increasing number of 'R's (Restructure, Redistribute, Reduce, Reuse and Recycle) (e.g. Latouche 2004)[147], are all entailed in Daly's stock-service-throughput equation and can be seen as useful and stimulating key-words for putting it into practice.

(135)

$$\underset{(1)}{\frac{service}{throughput}} \equiv \underset{(2)}{\frac{service}{stock}} \times \underset{(3)}{\frac{stock}{throughput}}$$

Equation (135): Service, Stock and Throughput (adapted from: Daly 1992, p. 36)

Just like John Stuart Mill at his time, Daly is convinced that it would be of great benefit to the human society to establish a SSE before it is inevitable. For this purpose he (1992) offers three institutions: (1) Aggregate physical depletion quotas for stabilizing the stock of physical artefacts and to keep throughput below ecological limits i.e. to address ratio 3. (2) A "distributionist" institution for limiting the degree of inequality in sharing the constant stocks (ratio 2 / 3)[148] and (3) some form of population control to address the "stock" of people e.g.: Boulding's (Boulding 1964) transferable birth licenses[149]. The latter is an issue that is often conveniently omitted, not only by the mainstream sustainability discourse but also in the more radical de-growth literature (Ariès 2004; e.g. Latouche 2004; Bonaiuti 2006; Grinevald 2006). The next section is therefore solely dedicated to highlighting the importance of demography

[145] The goal being to produce a maximum of service from a minimum of stock.
[146] The goal being to maintain a maximum of stock with a minimum of throughput (low entropy matter and energy).
[147] In a more recent publication this list has been amplified by three more 'R's: Re-evaluate, Re-conceptualize and Re-localize (Latouche 2008).
[148] There are diminishing returns (services) to material wealth e.g. a sweet given to the child of a billionaire does not cause the same excitement than if given to a poor child in Africa.
[149] Boulding suggested creating a market for birth licences, where every couple would initially be issued 2.1 licences. Hence for having more than 2 children i.e. more than the simple reproduction rate one would have to find other couples, who were willing to sell all or part of their licences.

for critics of economic growth and to underline the inappropriate treatment of the issue in the de-growth literature.

2.6 Population

Writing about the need for population control is still a taboo and being labelled as Neo-Malthusian is usually considered something negative. Moreover the Anti-Malthusian mainstream tends to argue that Malthus was too pessimistic with regard to technological progress and that his theories have been proven wrong by history (e.g. Economist 2008). This line of reasoning resembles the absurd argument that humanity will *not* "run out" of non-renewable resources, because this has never happened in the past either (e.g. Lynch 1999). Instead, it is much more likely that the effects of Malthus' population principle have only been postponed because of the enormous energetic subsidy that the human economy obtained and continues to obtain by tapping the underground storage of solar energy of millions of Palaeolithic summers, called fossil fuels.[150] This subsidy allows us to support our so called "modern agriculture", which uses more energy in fossil fuel inputs, than it produces in food calories (Giampietro 2002). Once this subsidy begins to decline we might see the "Malthusian devil" (in Toye 2000) unleashed again.

Hence stabilisation or de-growth of the economy inevitably requires stabilisation or de-growth of the number of humans respectively. The planet's carrying capacity of our species is defined by the maximum sustainable impact (I) of our society. Impact (I) in turn is given by the well known equation I=PAT: population size (P), times its affluence (or consumption) (A), times the environmental damage (T) caused (Daily and Ehrlich 1992). The reduction of (A) by sufficiency and frugality as well as that of (T) by acting more environmentally conscious and by technological progress cannot proceed indefinitely (Polimeni, Mayumi et al. 2008), so (I) will inevitably continue to grow if population is not stabilized or decreased.

However Boulding's top-down market-based approach mentioned above, may not be the most appropriate policy option for such a delicate issue. Instead one may find inspiration in the Euro-American neo-malthusianist bottom-up women's freedom movement of 1900 (of Emma Goldman and other activists), as suggested by Joan Martinez-Alier (Martínez Alier and

[150] Although Boserup (1965) showed convincingly that population growth is a cause of changes in the agricultural system (from slash-and-burn to intensive rotation with irrigation feeds more and more people), firstly her work in 1965 stopped before the period of "farming with petroleum" (Odum 1971) and secondly did not analyze the decreasing energy efficiency of modern agriculture (Pimentel, Hurd et al. 1973).

Masjuan 2009), Ronsin (1980), or Masjuan (Masjuan Bracons and Martínez Alier 2000; Martínez Alier and Masjuan 2009). It demanded "conscious procreation" to prevent low wages and pressures on natural resources, in opposition to the interests of the state, who wanted more soldiers, and the churches, whose objective was (is) to outnumber the members of other religious groups (Martinez-Alier 2008).

The treatment of the population problem by de-growth authors is either missing, patchy or incoherent. Georgescu-Roegen himself was already unclear about policy recommendations. Instead he focused on the question of *how many* people the planet could potentially support (e.g. Georgescu-Roegen 1971, Ch. 10), which in his view were as many as could be adequately fed by organic agriculture (Georgescu-Roegen 1975). He therefore implicitly proposed a steady-state population, which is clearly incompatible with economic de-growth *towards zero*: Just as the growing economy requires the augmentation of the labour force, the declining economy needs it to shrink – at least over the long run. Latouche, avoiding demography in earlier writings, did finally address it more recently (2008, Ch. 5). However he downplays the issue as an easy-way-out for the rich and powerful, who wish to uphold the present economic system – implicitly postulating that the current economic system could be maintained *without* population growth and immigration.

2.7 Criticisms, challenges and discussion

Rather un-confrontational counterattacks by the orthodoxy (Solow 1974; Stiglitz 1974; 1979) aside[151], most common academic critiques of the SSE are focused on thermodynamics – the science of energy. According to the second law, entropy increases in an isolated system. Entropy, which could roughly be defined as 'the level of disorder', has also been described as "time's arrow" (Eddington 1929) and only moves continuously in one direction. A standstill or steady-state is therefore an entropic impossibility, a fact that Daly (1981) was well aware of. Two points have to be made in this respect: Firstly, while energy cannot be recycled - i.e. depleted stocks of coal, oil and gas are lost forever - entropy can indeed increase in one system at the cost of another. Hence the energy dissipated by the sun due to nuclear combustion of its mass, could serve to withstand the entropic arrow until the end of the

[151] Orthodox, neoclassical economists like Solow and Stiglitz have avoided any direct referencing of Georgescu-Roegen, Daly or other growth critics, until they were directly challenged by Daly .

lifetime of the sun[152] - at least theoretically. This is in fact the argument brought forward by Robert Ayres (1998; 1999) (see discussion below).

The fiercest critique of the SSE came from Daly's mentor Georgescu-Roegen (1976; 1977) himself. Just like 'sustainable development' (WCED 1987) and 'small is beautiful'(Schumacher 1973), to him it was mere 'snake oil' (Georgescu-Roegen 1993a; 1993b; cited in Gowdy and Mesner 1998) and evidence of the hopeless search for "ecological salvation" by a human society which did not accept its mortality. Georgescu-Roegen´s "fourth law of thermodynamics", which - as a practical observation - is vigorously defended by Daly, reads: "in a closed system, the material entropy must ultimately reach a maximum" (Georgescu-Roegen 1977, p. 269). This "law" implies that "[c]omplete recycling is impossible*"* (Georgescu-Roegen 1971, p. 60), as the wear and tear of material objects causes an irretrievable dissipation of small particles (e.g. the rubber of a tire). Since even in a SSE non-renewable materials are dispersed in such a way, it cannot escape the "fourth law" leaving the declining state (Georgescu-Roegen 1977, p. 270) as the only viable alternative.

Georgescu-Roegen continues that "… even a declining state which does not converge toward *annihilation*, cannot exist forever in a finite environment (Georgescu-Roegen 1976, p. 23 own emphasis)." The last part of this quote is of course a contradiction, as something that moves towards annihilation equally cannot exist forever.[153] This of course does not mean that Georgescu-Roegen advocated the earliest possible disappearance of the human species from the planet. The quote originates in a rather polemical article, where he used strong words in order to emphasise his disliking for the concept of a steady-state. The term "annihilation" in this context probably refers to the entropic heat death of the universe. So rather than the *desired* policy end-goal of economic de-growth, it is the eventual *inevitabl*e future of the planet earth over the very long run (see also footnote 15). Nevertheless the above quote is important as it shows that economic de-growth as proposed by Georgescu-Roegen is a path

[152] About 5 billion years (http://en.wikipedia.org/wiki/Sun), "only" 500 million of which are supposed to provide adequate conditions for complex life forms on the planet, then it will get too hot.

[153] Having said that, on the same page Georgescu-Roegen exempts the "berry-picking economy" (Georgescu-Roegen 1976, p. 23) from his dire verdict. Indeed, such hunter-gatherer societies, in the absence of population growth, could probably exist in a steady-state throughout the sun's lifetime. This of course would imply that our present economy and population must have had collapsed already. The population of Georgescu-Roegen´s "berry-picking economy" could thus be regarded as the minimum possible level of "stock" of a quasi-eternal steady state.

without a constructive goal for policy making. This appears inconsistent with his earlier mentioned goal of a steady-state-population.[154]

The "fourth law" could be regarded as the essence of a third view, which was added much later in the polemic over the steady-state between Daly and Georgescu-Roegen. On many occasions Robert Ayres (Ayres and Nair 1984; Ayres and Kneese 1990; Ayres 1994; 1997; 1998; 1999) criticised both scholars for their interpretation of thermodynamics: Firstly the law of conservation of mass (Lavoisier 1984 [1790]) states that matter is neither produced nor destroyed. Secondly the earth is not an isolated but a closed system[155], as it receives a huge amount of solar energy influx[156] of which only about 3% or so are used by plant metabolism (Ayres 1998). Thus, Ayres (Ayres and Kneese 1989; 1998; Ayres and Frankl 1998; Ayres 1999) argues that advances in solar energy technology, will eventually secure huge amounts of energy.[157] Enough to re-concentrate the dissipated matter, which is trapped by the gravitation of the earth, i.e. 100% recycling becomes feasible if enough energy is available. This position, the so called 'energetic dogma'(Mayumi 2001), is actually an unintentional defence of the SSE against Georgescu-Roegen's "fourth-law-based" rejection thereof. If economic growth can be sustained almost indefinitely (as Ayres partially suggest), then so could also a steady-state.

Ayres consideration may be true in theoretical terms, of which Georgescu-Roegen (e.g. 1977) was and Daly (1981) and Latouche (2006) are well aware. However there are many practical limitations to Ayres' technological optimism, some of which were addressed by himself more recently (Ayres 2006; 2007). Two more shall be mentioned here: First, given sufficient energy, all concentrated deposits of minerals would be depleted first and then dissipated in the

[154] Kozo Mayumi, one of Georgescu-Roegen´s last students, holds the following view regarding this matter: "Given the finite amount of resources including solar energy, the time horizon is finite regardless of people's attitude toward continual growth, steady state, decreasing consumption. Thus far nobody including G-R, tried to investigate the three issues: Sustainability for whom? Sustainability of what? Sustainability for how long?" (Mayumi 2009) I would argue that Daly's quasi SSE is an important reorientation of our economic attitude toward a long-term sustainability policy goal. If his view is properly linked with the ongoing de-growth debate, it will be a good starting point for answering these questions on a suitable time scale for human existence on this planet.

[155] The difference is that an isolated system exchanges neither energy nor matter with the outside, whereas a closed system does receive an external energy influx. The earth is a closed system, with no inputs of matter (except for the odd meteorite), but an influx of energy from the sun.

[156] The amount of energy received by the sun each day is about 6000 times larger than all the primary energy consumed (source (Giampietro 2002; BP 2007)).

[157] The earth's surface is no limit to Ayres (Ayres and Kneese 1989; Ayres and Frankl 1998; Ayres 2007) as he is convinced that one day we will be able to mount solar collectors on satellites or the moon and microwave the energy back down to earth.

respective sinks of the lithosphere in a high entropy state (minuscule concentrations). Then one would have to start "mining" the sinks or the "wastebasket", as Ayres (1999) indeed proposes, in order to recover (recycle) the dissipated materials. Considering the social and environmental impacts that "concentrated" mining all around the world has already (e.g. Orta Martínez, Napolitano et al. 2007; Walter 2008), it is not difficult to imagine the practical impossibility of converting a large part of the lithosphere into a huge mine. As Ayres (1998) himself emphasised, the capacity of sinks to absorb waste products of the human economy (CO_2 in the atmosphere, nitrates in the water body, heavy metals in the soil) may have become more limiting than natural-resource scarcity.[158] Secondly, it is rather questionable, whether the material structures necessary to harvest solar energy could be maintained over the long run just by the energy produced by them (Georgescu-Roegen 1993; Daly 2006). This is especially true with regard to some rare elements (e.g. indium), on which the most efficient PV cells currently depend (Andersson and Rade 2002).[159]

An aspect usually overseen by technological optimists is that with current unsustainable lifestyles, it would be very dangerous indeed if humans found an inexhaustible and cheap source of energy, even if it were environmentally benign. Availability of surplus energy has always been one of the most important limiting factors to the expansion of the human economy (Tainter 1988; Reader 1997)[160]. Hence if we discovered some 'miracle' source of energy now, a massive explosion of the human population (P) and its consumption (A) and therefore a huge impact (I) would probably be the result. The stress that our economy is exerting on ecosystems, since we have discovered and learned to utilize fissile fuels, is good evidence thereof. In other words it is more than likely that there is some direct relationship between the amount of energy consumed and environmental damage caused (Luzzati and Franco 2005; Cabezas 2006).

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[158] Ayres' argument in fact is that we only have to fear the collapse of environmental services, which will bring upon us a disguised version of the Malthusian dilemma .

[159] For a more detailed and technical defense of Georgescu-Roegen's fourth law against the "energetic dogma", see Mayumi (Mayumi 2001)

[160] Tainter (Tainter 2000) argues that humans need energy for problem solving. The encounter of and utilization of coal for example was a result of a search for an energy resource in order to alleviate the hardship caused by overpopulation and deforestation in the Middle Ages and Renaissance. If we would not have found that resource then our society would have most likely collapsed as the Roman Empire did (Tainter 1988). Tainter (Tainter 2000)therefore concludes that for our society to become sustainable, we may need to consume more rather than less in order not to loose our capacity to solve problems. In the face of Peak Oil (Campbell and Laherrere 1998) I think this verdict may mean that the collapse of our present society is inevitable.

De-growth authors have barely touched the controversies analysed above and have religiously adopted Georgescu-Roegen's position against the steady-state. Moreover they equally fail to adequately ask questions about the end-point of what they propagate, conveniently omitting the word "annihilation" when they cite Georgescu-Roegen. Instead the focus of the argument is placed on the fact that rich industrialised countries have evidently surpassed sustainable limits already, and de-growth is therefore essential. Although certainly true, this alone is no reason for rejecting the objective of a SSE on a global level at some mutually agreed upon sustainable level of throughput. Rather it is an argument in favour of combining the two concepts (see Figure 45). In order for the SSE to be equitable not only on a national (see Daly's second institution above) but also on an international basis, the rich North will need to de-grow in order to allow for some more *economic* (vs. uneconomic) growth [161] in the poor South. This is to balance the service obtained from the steady-state level of stock and throughput between the rich and the poor, as illustrated in Figure 45. Economic de-growth can therefore be seen as a *path* that leads to a globally equitable SSE.

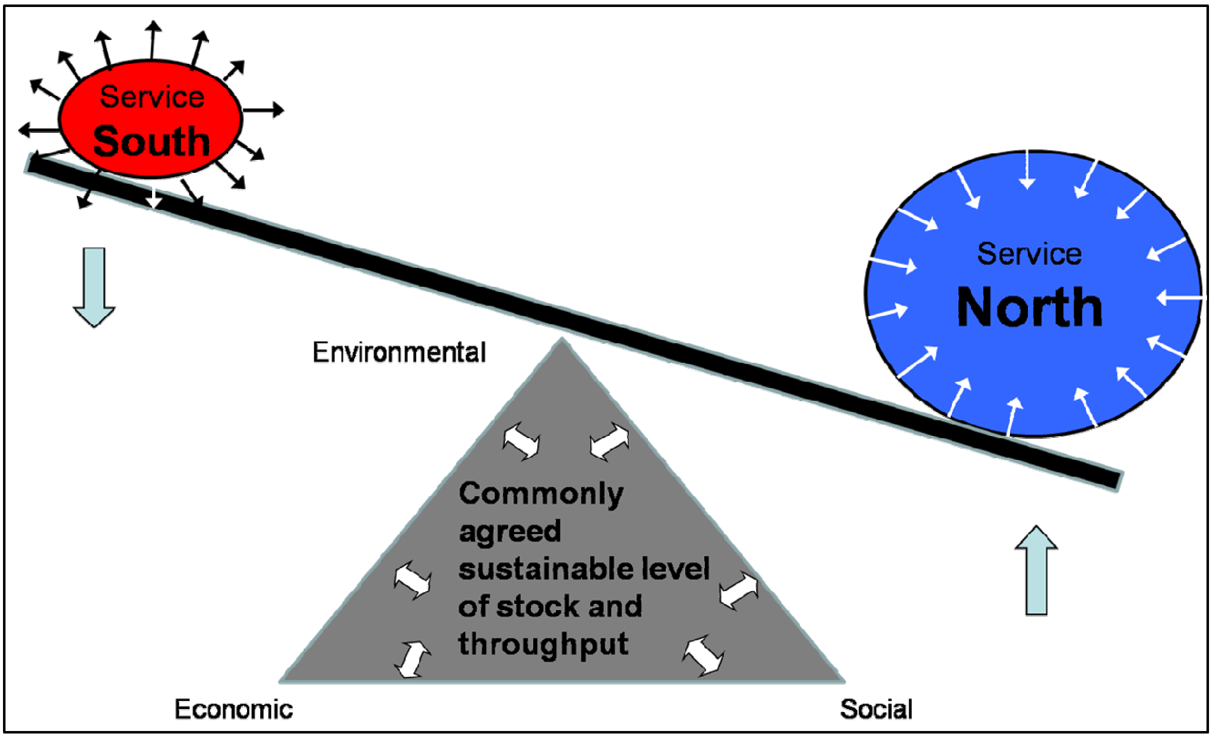

Figure 45: Balancing an equitable quasi steady-state world economy.

In summary many of the above criticisms of the SSE can be attributed to an erroneously narrow and technocratic definition of the concept. Daly later advocated a *quasi* SSE (Daly 1993; Daly 2007) which is "… neither static nor eternal – it is a system in dynamic

[161] Many studies show that in the North economic growth is not contributing to welfare anymore i.e. it is uneconomic (compare: Nordhaus and Tobin 1972; Daly and Cobb 1989; Neef 1995; Daly 1996; Daly 2001).

equilibrium within its containing, sustaining, and entropic biosphere" (2007, p. 117). In other words the stock-throughput triangle of Figure 45, representing both a quasi SSE and (strong) social, environmental and economic sustainability, will most likely have to shrink over time. The smaller the triangle is however, the longer it can be maintained. To actually define its size, even for a short period, is admittedly extremely problematic - if not practically impossible.

2.8 Unattainable goals and moral growth

In my view it is therefore important *not* to define the SSE as a goal that can actually be arrived at in terms of an end-point. This is practically impossible due to the difficulties in resisting entropic dissipation of materials (Georgescu-Roegen 1971) over the long run[162] and the socio-economic, political and ecological complexity involved in determining and deciding upon a steady-state throughput level. Instead I shall turn to psychology in order to define a SSE as an "unattainable goal", thereby embracing that complexity, without taking away the validity of the goal itself.

From Viktor Frankl's (1963) Logotherapy, we know how important it is for us humans to find meaning in life. Certain goals, for example having one's own house, can give such meaning. To some that goal might remain unattainable, possibly causing distress and illness in the absence of successful goal disengagement (Wrosch 2003; Wrosch, Miller et al. 2007). Some goals however are per definition unattainable during one's lifetime, like those in religious contexts (salvation, enlightenment, ever lasting happiness...). Far from being distressing, following these goals (i.e. being religious) has been shown to be beneficial to psychological well-being and health (Moreira-Almeida, Neto et al. 2006)[163]. Moreover, they stimulate the creation of long-term visions and paths in order to approach/approximate them. The SSE could serve as a common goal of that sort, which could hardly be said about annihilation, the apparent "destination" of economic de-growth according to Georgescu-Roegen.

[162] The factor time was very important for Georgescu-Roegen (Gowdy and Mesner 1998), nevertheless when rejecting the SSE, he neglects the possibility that a "quasi-steady-state" could theoretically exist over the short run, maybe even over several generations.

[163] In fact it could be argued, that "mundane" goals, which to many are unattainable as described by Wrosch (Wrosch 2003; Wrosch, Miller et al. 2007) i.e. building a house, etc. have replaced earlier religious goals in modernity.

It is worth mentioning here that what has been argued above is equally true for a strong definition of sustainability.[164] In fact the SSE and (strong) sustainability could be regarded as identical concepts (compare: Kerschner 2006), for which both could be defined as unattainable goals. It is regrettable that what should have been the path towards this goal, 'sustainable development' (WCED 1987), has become to mean 'environmentally friendly economic growth' (Georgescu-Roegen 1993; Latouche 2004) or 'sustaining the unsustainable' (Blühdorn 2007). Latouche´s (2004) elaboration of Georgescu-Roegen´s (1993) critique of sustainable development is - in my view - indeed one of the de-growth literature's most important contributions. However "sustainability" itself (without development) still can be a valid goal, if it is defined as above.

Returning to the studies of Wrosch (2003) and others one could further intuitively argue, that many of us, at least in the industrialised world, are driven by unattainable goals which are formulated in an individualistic and relative sense. We strive to be wealthier, prettier, more skilled, more admired or more powerful than everyone else. Since not everybody can be relatively better than everyone else, these are clearly unattainable goals, many of which collectively constitute the goal or end-point of the economic growth path. The SSE on the other hand can be an objective that is both motivating and solidary.

Unfortunately, as Daly (1992) and Latouche (2006) themselves admit, the SSE and the de-growth economy respectively are socio-politically utopian at the present state of affairs. This is of course true no matter how we define the SSE or economic de-growth. They are not ideas that people would voluntarily vote for, unless there was what Daly (1992) calls 'moral growth'. Moreover some of those who might be willing to push for a radical change towards a different economy, would probably not be enthused by the imposition of Daly's institutions, which have an air of authoritarian top-down decision making. This and the unappealing sound of 'standstill' might explain why the concept steady-state has not resulted in the creation of grass-root movements such as those found under the heading of 'la dècroissance' in France, 'la decrescita' in Italy or 'el decreixement' in Catalonia[165]. Their revolutionary spirit and provocative slogans may indeed be more suited to overthrow Georgescu-Roegen's (Georgescu-Roegen 1977)'growthmania' (citing: Mishan 1967) or Latouche's (2004)

[164] For an overview on the two definitions see Neumayer (Neumayer 1999).
[165] There is a Centre for the Advancement of the SSE (www.steadystate.org), but this is more an academic think-tank, than a social movement.

'tyranny of growth', than does the concept of a SSE. Nevertheless these movements, are also unlikely to be relevant on a large scale, in the absence of 'moral growth'.

The advancement of the ethical properties of our society - in favour of de-growth as a path towards the "unattainable goal" of a SSE - may appear utopian at this moment, but could indeed occur in the presence of a radical external shock or crises. In fact, Peak Oil (e.g. Campbell and Laherrere 1998), Peak Coal (Kerr 2009) or the current economic crises, which is most likely related to the former (e.g. Rubin 2008), could possibly produce such a situation. If unanticipated and without plans for adaptation however, the very opposite i.e. moral de-growth might take place, which could have us witness the return of authoritarian regimes like in the 1930s (Leggett 2006; Ledera and Shapirob 2008).

Even more than a well managed crisis, moral growth will require an 'ultimate ends' discussion i.e. deliberations about the true purpose of the economic process, depending on each context (cultural, political,..). De-growth movements and writers have gone a long way already, when promoting social justice, solidarity (e.g. Ariès 2004; Latouche 2006), 'joy of life' (Georgescu-Roegen 1979), the acquisition of "relational goods" more than material goods and the cultivation of human relationships (Bonaiuti 2006). However this may not go far enough and other immaterial endeavours such as 'love' or 'compassion', which appear to be too esoteric even for the revolutionary spirit of the de-growth community, might have to be called upon as well[166].

2.9 Conclusion

Based on the above arguments it is argued here that the categorical rejection of a steady-state economy by Georgescu-Roegen and by emerging movement of "de-growth economics" should be reconsidered. In fact, instead of contradictory, the two concepts complement each other. As illustrated in Figure 45, economic de-growth in the North, provides a *path* for approximating the *goal* of a globally equitable SSE, by allowing some more *economic* growth in the South. Moreover Daly's SSE has deep roots in economic history and offers concrete macroeconomic policies, both of which the de-growth literature lacks. Daly's SSE, with its air of top-down decision making, on the other hand, could learn from the focus on grass-root

[166] I am aware that this and earlier affirmations may sound as if I was to promote religiousness or some specific religion. This is not the case, instead these are values that can contribute to the good of all and exist not only inside (all) religions but also outside. Daly (Daly 1993) on the other hand is explicit about the fact that "ultimate ends" for him are religious. Nevertheless his theories do not depend in any way on this fact.

initiatives by the de-growth movements and literature. This is especially so when addressing Malthusian concerns, which Daly's SSE notably does, but in a rather top-down manner. Unfortunately the issue of population is not given the importance it merits by de-growth writers and activists.

Related to the above mentioned rejection of the SSE, are criticisms based on the entropy law and the "fourth law" (Georgescu-Roegen 1977; Ayres 1999; Latouche 2006). However these problems, together with the utopian critique, can easily be healed, if we focus on the goal of a quasi SSE, resting in a dynamic equilibrium. Adopting the provocative spirit of de-growth writers, this *goal* should openly be defined as "unattainable". Same is true for sustainability and many other worthy policy goals promoted by economists (e.g. full employment). Despite being elusive, they can (and should) be approximated. Leading towards these "unattainable goals", are a multitude of different *paths*, consisting of top-down and bottom up approaches in differing proportions for every particular geographic and socio-cultural context. Economic de-growth is only one of these paths, but undoubtedly a necessary one for the rich North over a certain period of time. For this to be able to happen we may need growth in what is indeed limitless – the moral properties of our society.

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2.11 References

Please note references of this article have been integrated in the bibliography of Part 4.

3 Conclusion, Summary and Outlook

After arriving at the conclusion that in order to create a sustainable society it is necessary to create a steady state economy I addressed the criticisms it was subjected to by Nicolas Georgescu-Roegen (NGR) – the reason for degrowth community to reject the concept too. I argued that if defined in appropriate rather than in technocratic and narrow terms, most of

NGR's thermodynamic objections can equally be dispersed. In fact Daly himself has later advocated a *quasi* SSE (Daly 1993; Daly 2007) which is "… neither static nor eternal – it is a system in dynamic equilibrium within its containing, sustaining, and entropic biosphere" (2007, p. 117). A globally equitable, dynamic quasi SSE, would be based on a mutually agreed level of throughput, in accordance with the available resource base. For how long such a state can be maintained, depends on the size of the remaining resource base and the throughput level (i.e. the smaller the longer). The factor time was very important for Georgescu-Roegen (Gowdy and Mesner 1998), nevertheless when rejecting the SSE, he neglected the possibility that a "quasi-steady-state" may be feasible over several generations.

What remains is the difficulty, or better impossibility of overcoming the socio-economic, political and ecological complexity involved in determining and deciding upon a steady-state throughput level. Doing justice to this complexity, without diminishing its validity, I have proposed (Kerschner 2010) to define the SSE as 'constructive unattainable goal'. The term is derived from social psychology, where it is usually described in its destructive form (Wrosch 2003; Wrosch, Miller et al. 2007) and Viktor Frankl's (1963) Logotherapy, where goals are known to give meaning to live. Constructive 'unattainable goals' are familiar to us both from religious (enlightenment, everlasting happiness, etc.), as from political contexts (full employment, global justice, world peace etc.). Certain evidence suggests that following such goals of creating a better future day by day, without the certainty of ever arriving, is beneficial to psychological well-being and even physical health (Moreira-Almeida, Neto et al. 2006). The constructive unattainable goal of a SSE may sound like utopianism; however the difference is that the SSE is mostly a biophysical concept (with the exception of Daly's proposed minimum and maximum income). So it's not trying to describe an ideal future society. Whatever new institutional/political settings may lead to it, finally or intermediately, is left to the new imaginary being created along the degrowth path.

Among the many research streams that are rapidly opening up within the economics of degrowth (Kallis, Kerschner et al. 2012) one area should link up with insights from the above, maybe calling itself "ecological economic psychology" or "economic degrowth psychology". Main aim of such a research stream would be to discover the roots of our destructive economic actions (overconsumption, accumulation, etc.), which may be due to programmed but obsolete material anxieties and emotional disequilibria. Shedding light on psychological wellbeing factors (Masferrer-Dodas, Rico-Garcia et al. 2012), identifying the role of reference states, aspirations (Matthey 2010) or unattainable goals, are steps in the right direction but are still only scratching the surface. Many known degrowth practices (e.g. cooperatives, etc.) for example may be successful precisely because they respond to certain material anxieties.

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PART 5

Summary and Conclusion

Peak-Oil is a complex, often misunderstood phenomenon. After clarifying that Peak-Oil was both a stock as well as a flow problem, the concepts of resource quality and quantity were offered for getting a grasp of the many below and above ground issues that influence its timing and possible impacts. A review of the latest evidence suggested that there is a significant risk of Peak-Oil occurring before 2020, giving us little time for adaptation. Systems theory and thermodynamics illustrate that this is a serious problem, as we may not solely rely on other energy sources for substitution or efficiency improvements. The resilience literature therefor recommends adaptive resource management processes in cases of dependencies on risky resources, as in our case of oil for the world economy. The lack of appropriate institutional response and development of adaptive policies or contingency plans is therefore rather surprising. A first attempt of an institutional analysis, speculated that this may be due to the dominant paradigm in neoclassical economic theory of relative resource scarcity, governance of non-renewable resources via markets and technological optimism. For this reason, a detour into philosophy and the analysis of surveys was taken in order to investigate the different possible attitudes towards technology; their origins and distribution among sustainability scientists. One main contribution of this text to the present Peak-Oil situation was the in-depth exploration and application of Input-Output analysis for estimating potential impacts and vulnerabilities of world economic systems to Peak-Oil. Such analysis is the first step towards adaptive resource management, it is about starting to get to know the system. The reproduced case studies showed how certain clusters of industries seem to be vulnerable to Peak-Oil (e.g. transport, petrochemicals, wholesale and retail trade, etc.) and because of their importance within the structure of the economy render the entire economic system vulnerable to the phenomenon. Such information is of utter importance for designing adaptive policies. Finally the radical resource base adaptive policy option of economic degrowth towards a steady state economy (SSE) was presented and a settlement of an old dispute between Herman Daly and Nicolas Georgescu-Roegen offered. The SSE was defined as an unattainable goal, which can never actually be reached but can and should be approximated.

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